DEMAND SIDE FLEXIBILITY THROUGH SMART HOMES

2017

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This study was carried out for ESMIG, Energy@Home and EEBus by Joule Assets Europe and VaasaETT. The views expressed in this document represent the findings of the study, and do not represent the views of ESMIG, Energy@Home or EEBus.

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Executive Summary

This study quantifies the costs and benefits of demand side flexibility and energy savings through the ubiquitous rollout of smart appliances at a national level. The quantification is carried out within 4 EU Member States, France, Germany, Italy, the UK, and a reference country combining the most beneficial characteristics of each Member State. As a basis for the calculations, the study uses hourly market values and actual household consumption patterns. In order to model demand side flexibility, the averaged results of 140 residential pilots were used. What the study does not calculate or take into account is the benefits that would accrue to the network operators on the low and medium voltage systems. These calculations therefore in fact significantly under-estimate the future potential benefits for the networks, given the introduction of electric vehicles, and the low voltage intermittent distributed generation.

Therefore, this study answers 2 important questions: If smart appliances were ubiquitous today, with today's electricity prices, what would the financial benefits be for the participating consumers and society, against the actual cost of the smart appliance technologies? What amounts of flexible capacity (MWs) and energy savings (MWhs) could these appliances enable?

The findings were calculated assuming the full range of markets and programme types was open and available to consumers in accordance with the requirements of the Energy Efficiency Directive and the Network Codes.

The findings indicate that by creating demand side flexibility through smart appliances, these appliances have a significantly shorter payback time than almost all forms of generation. While a solar panel in Portugal today will require approximately 6.5 years to pay back, a coal or gas fired plant 25 to 30 years in Germany (at best) and a nuclear generator will simply not pay; the average time required to pay back smart appliances is between 1.2 and 3 years depending on the Member State, without including the value of societal or industry benefits. If surrounding benefits are included, payback time is under a year for the majority of consumers. This is less time than it takes to pay back an average energy efficient light bulb on a commercial site.

Benefits accumulate over time while the purchasing decision is taken once. For example, if 30% of UK households made full use of smart appliances for creating flexible demand as assumed here, the savings would be €490 million per year, not counting potential savings from gas heating. This is €4.9 billion over 10 years. At the same time, the consumer participation would create 1,198 MW of total flexible capacity with a payback time of 3 years. This is the equivalent of 2.3 500-MW power plants. Today these same plants are considered non-viable in the UK, due to the low market prices. Therefore, while a capacity resource from smart appliances could be paid back within 3 years with these same market prices, power plants are not viable even if investors will finance them for decades. Indeed, in response to this issue, the UK government has decided to subsidise generators through a capacity market.

Similarly, annual savings in Italy would be €599 million and €5.99 billion in 10 years. The demand side flexibility created would be 1,227 MW of total capacity, with a payback time of 2.2 years for the technologies required. This is equivalent to 2.5 500-MW coal or gas fired plants.

In Germany, annual savings would be €1.1 billion annually and €11 billion over 10 years. Smart appliances could create 1,705 MW of flexible capacity, equivalent to 3.5, 500-MW power plants. All with an average payback time of 1.9 years, even at today's prices where the building of comparable new generation capacity is considered impossible in Germany, due to the low electricity prices. Like the UK and France, the German government is therefore looking to subsidise generators through a new capacity market.

If the same percentage of French households had smart appliances, the total savings for these consumers would be €1.23 billion annually. Over 10 years the savings would be €12.3 billion. With a 30% uptake rate, 2,933 MW of total flexibility would be created with a payback time of an average of 1.2 years in France. This is the equivalent of almost 6 500-MW coal or gas fired plants or 3 nuclear power plants. Again, today EDF has requested subsidies in the form of a French capacity market, due to the impossibility of maintaining their nuclear fleet at today's prices. Yet smart appliances could be paid off in less than two years, with the exact same prices as French generators find inadequate.

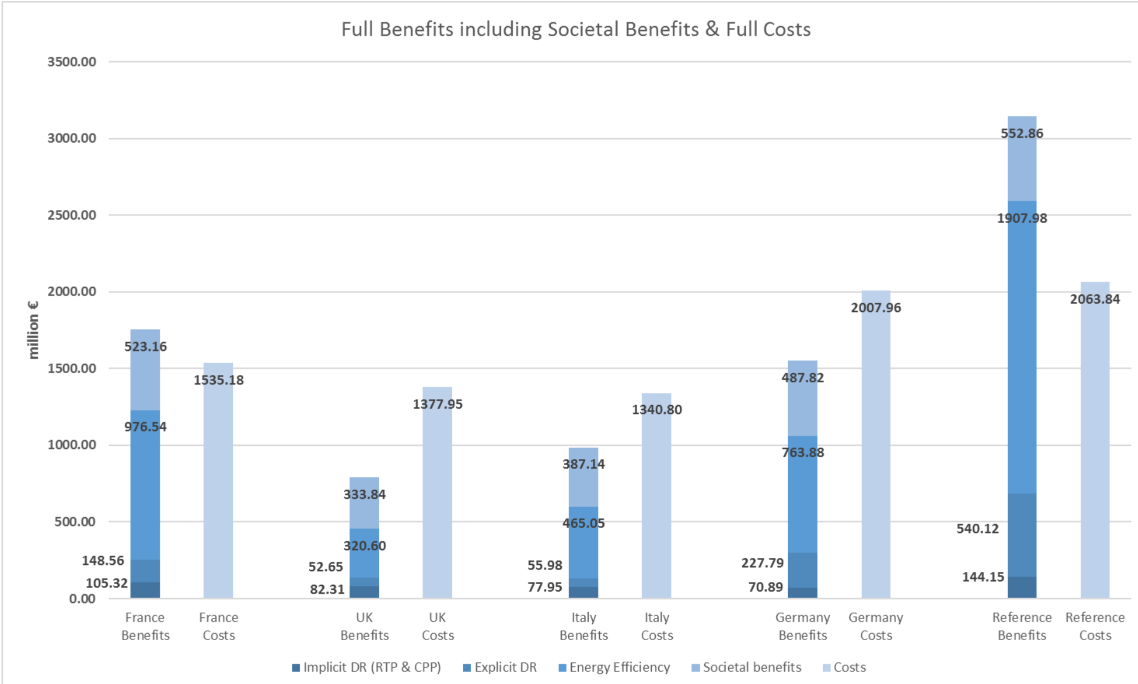

Figure 1: Full benefits including societal benefits and related costs per country

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	0.8	1.2	1.0	0.9	0.6

Though smart home and appliance programmes would cost to rollout, sell and run, these calculations are still conservative, they include no avoided costs in network upgrades or indeed the cross-border benefits of one country's efficiency lowering balancing costs in the neighbouring country. Therefore, counted across Europe, improving the intelligence of the European home is as good or better an investment than many other similar programmes.

However, though this study finds that the results of this cost benefit analysis are overwhelmingly positive, challenges remain and certain key lessons are described below:

1. Overcoming challenge of the purchase decision:

Uptake rates drive down costs by creating economies of scale and supporting the growth of service providers. There is also a direct correlation between the number of people actively using smart appliances and the development of societal savings and environmental benefits. Yet a positive cost benefit analysis at a national level, does not equal a compelling sales proposition for a single household. Moving consumers to a purchase and implementation decision on the merits of energy related services alone, will remain a challenge. The issue should therefore be addressed directly within the industry and at the regulatory level.

a. **Smart technologies should be made ubiquitous** and intelligence built into appliances. As there is a realistic and viable opportunity for the majority of European consumers to optimise their electricity (and gas) consumption at home, saving between 10% and 20% on their energy bills, it is highly logical to build intelligence into appliances and ensure interoperability from the start. Consumers should not be required to purchase such kits separately.

b. **Multi-purpose service packages** may be more compelling to buy than a purely energy centred offering. This does not have to be a barrier to rollout; internet and communications companies bundle smart home applications with internet and phone services, security firms bundle warnings concerning faulty appliances and control capabilities with security services, health service companies, (particularly for the elderly), bundle communication, control and warnings to the occupant and caregivers. Circumstantial evidence suggests that these offerings already compete today with those offered by utilities and will continue to do so.

2. Open competitive markets

Holistic regulatory support has been drafted by the European Commission and should be further refined and implemented at a national level. Today in Europe, the benefits quantified here are **impossible** to achieve, no matter the technologies in place, due to prohibitive regulatory barriers in the balancing markets and a general lack of dynamic pricing offers in the retail markets. This should change.

a. **Participation regulation:** While some markets are shut entirely to consumer load, other markets are open in theory but not in fact, for example they may 'allow' consumer load to act as a resource but require a consumer to inform the TSO weeks or even a month in advance, how much electricity they will be using each hour of each day. When these obvious barriers are removed, more subtle forms of bias often remain, such as only allowing consumers to participate during particular hours (unless they work with the national utility in which case these rules no longer apply), or paying consumers less MW for MW, than a generator providing the same quality service.

b. **Healthy competition:** Motivated service providers are key for market growth. However, independent retailers and aggregators may have difficulties entering a country due to biased market design which, for example, provides access to energy at higher costs and at shorter notice to them than to the established players, or makes gaining access to high quality meter data more complicated for a new entrant retailer than an established player or creates prohibitive barriers toward aggregators blocking them from offering consumers services at all.

The list of barriers is long. In short – as governments and regulators want consumers to have access to services, they must continue to fight for consumer rights to access markets and encourage market competition between service providers including incumbent utilities, new entrant retailers and aggregators.

3. Supported as a public service

The societal benefits created through demand side flexibility significantly outweigh benefits to the households participating in the programmes. In other words, these consumers do even more good for society than they do for themselves. For example in France, consumers with smart appliances could earn €254 million from DSF (not counting energy efficiency programs), while the societal benefits of the lowered clearing prices (through DSF) would be €523 million annually. These benefits are spread across all consumers. In the UK, the difference is also dramatic, participating consumers earn €135 million while from DSF the societal benefits are €334 million annually. In Italy, direct earnings for participating consumers are €134 million while societal benefits are €387 million, and in Germany participating consumers could earn €298 million directly while societal benefits are €488.

The calculations of societal benefit in this study are conservative, as the clearing cost reductions from energy efficiency, lowered distribution and transmission costs, the impact of programmes related to gas usage and cross boarder benefits have not been included. Therefore, the discrepancy in payments to participating consumers compared with societal benefits, would increase if a wider analysis was performed.

In this sense consumers, which participate in DSF programmes are providing a public good. Smart appliances are key, enabling technologies for this public good. This should be acknowledged through public support, for example by including smart appliances in white or green certificates programmes, encouraging participation in capacity markets and other forms of public acknowledgement.

In conclusion: Smart meters and smart appliances are essential means for energy savings and for the further development of new energy services, dynamic prices and demand side flexibility programmes. DSF and home optimisation enabled through smart appliances are highly competitive when compared to either generation assets or indeed most energy efficiency measures[1]. In the ongoing deployment of the smart electricity metering infrastructure, not only the general roll-out is important but also the functionality of the meters themselves. A high frequency at which data can be updated and made available, as well as a standardized interface for the visualization of electricity consumptions, market conditions and price options, are fundamental to enable consumers to participate in the flexibility markets. The programmes they drive also provide significant benefits to society. That said, creating benefits in total is not the same as providing an immediate compelling sales proposition to individual consumers. Therefore, smart appliance capabilities should be built in to all appliances and communication interoperability should be insured. When this takes place, communications, health and security firms as well as retailers and aggregators will create viable bundled services with greater ease, ensuring significant uptake and usage. The European Commission and National Governments should enable this development through including smart appliances in public energy efficiency schemes and continuing to work toward open, competitive and consumer centric market structures.

[1] As an investor, Joule Assets has a database of energy related investments and their return times. These comparisons are taken from this internal information.

Section 1: Demand Side Flexibility and smart appliances in Europe

1.1 Introduction

Energy efficiency has been called 'the no regrets option' and 'the 5th fuel' by the European Commission. It is quantifiably the cleanest and cheapest energy resource available to us today and therefore benefits from strong regulatory backing both at national and European levels.

At the same time, growth in renewable electricity generation brings with it an increasing need for demand side flexibility to lower the cost of solar and wind integration and to avoid the need for unnecessary back-up generation – generation used for only short periods of time. The ability to both increase and decrease demand is an important and price competitive resource in providing balancing services. TSOs benefit directly from increasing the liquidity of their balancing portfolios and lowering costs, when they enable demand side resources to participate (though they often also incur an upfront investment costs in IT improvements). Multiple successful trials and rollouts have been completed quantifying the potential of demand side flexibility (DSF) within the residential homes. Therefore, there is a recognized, robust and growing need for flexible demand side resources, at the same time as the costs of residential participation is being reduced.

Residential participation is strongly supported today by a complimentary set of regulations, which provide **end-to-end support** for deployment, though many of these new rules have yet to be implemented. However, within the last three years, European legislation has progressed from stating that energy efficiency and demand side flexibility are important in principle to creating a cohesive set of regulatory initiatives providing a comprehensive foundation for market growth. This is an achievement in its own right.

This study quantifies the costs and benefits of demand side flexibility and energy savings made possible through the ubiquitous rollout of smart appliances, at a national level. The quantification is carried out within 4 EU Member States, France, Germany, Italy, and the UK, and a reference country (best case) where beneficial characteristics of each Member State is combined. As a basis for the calculations, the study uses hourly market values and actual household consumption levels for those same years. In order to model demand side flexibility, the averaged results of 140 residential pilots (involving over 950,000 households) were used.

Therefore, this study answers 2 important questions: If smart appliances were ubiquitous today, with today's electricity prices, what would the financial benefits be for the participating consumers and society, against the actual cost of the smart appliance technologies? What amounts of flexible capacity (MWs) and energy savings (MWhs) could these appliances enable?

The findings were calculated assuming the full range of markets and programme types, were open and available to consumers in accordance with the requirements of the Energy Efficiency Directive and the Network Codes. These include Implicit Demand Response, in the forms of Real Time Pricing (RTP) and Critical Peak Pricing (CPP) and Explicit Demand Response within the balancing and ancillary services markets (wholesale markets were included within the implicit programme analysis). This free access to market is of course not the case today – as household consumers have little access or market power or viable services available to them. Therefore, the findings highlight the value of implementing legislation at a national level – as well as the smart infrastructure investments required for enabling the smart appliance technologies.

The content of the study is organized as follows: Section 1 explains demand side flexibility in the smart home/smart appliance context, describing the types of services analysed, Section 2 describes the aims and the methodology of the study, Section 3 highlights the main findings, concerning costs and benefits of both implicit and explicit demand response, energy savings at a national and societal level. Lastly it provides the conclusions.

1.2 Regulatory Context

As stated above, for the first time, the European Commission has completed a set of regulatory and policy initiatives which lay the foundation for comprehensive growth. Below is a short overview of the main regulatory initiatives in place today and their main contents.

General background

In 2009, the European Council agreed to the long-term objective of reducing EU greenhouse gas emissions by at least 80-95% by 2050, compared to 1990 levels. In October 2014, the 2030 policy framework for climate and energy was adopted, in which the EU committed to reduce greenhouse gas emissions by 40% compared to 1990 levels by 2030, to achieve at least 27% renewable energy capacity but without country specific targets and 27% energy savings compared to 2007[2]. In order to make this commitment a reality, the European Commission presented roadmaps for a competitive low-carbon economy, resource efficiency, energy and transport.

Framework Strategy for the Energy Union, the European Commission (EC) sets the vision for the future and integrates a series of policy areas into one cohesive strategy. The EC's Communication considering 'A Framework Strategy for a Resilient Energy Union with a Forward- Looking Climate Change Policy' (COM(2015) 80 final) states that energy markets and power grids have to be capable of integrating renewable generation. It also states that energy markets should promote competition and enable a level playing field for a range of resources, including renewable and demand side resources. Within this context, smart appliances enable the more efficient use of on-site generation assets and allow the consumer to participate in these markets along with service providers through Demand Response. "*The Commission will continue to push for standardisation and to support the national roll-out of smart meters and to promote the further development of smart appliances and smart grids, so that flexible energy use is rewarded." (…) "However, this will only work if market prices send the right signals.*"

The Energy Efficiency Directive (EED)[3] looks to establish a common framework of measures for the promotion of energy efficiency within the European Union. This was to secure the Union's 2020 target of a 20% for energy efficiency. Applicable measures included:

- If Member States roll out smart meters they should ensure that the metering systems provide final customers information on actual time of use, thereby supporting demand side flexibility programs.
- If final consumers request it, metering data on their electricity input and off-take should be made available to them or to a third party acting on their behalf.
- Member States should ensure that Demand Response is enabled both within the wholesale and balancing markets. This includes:

  Requiring network operators to treat DR providers in a non-discriminatory manner and

  - Ensuring technical modalities defining the demand side participation in balancing, reserve and other system markets are defined on the basis of

[2] Vito, Viegand & Maagøe, Armines and Bonn University (2016): Ecodesign Prepatory Study Smart Appliances (Lot 33). P10

[3] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

the technical requirements and capabilities of demand response (rather than generation assets only) - in cooperation with aggregators;

- Allowing aggregation and enabling aggregators to participate in these markets
- Ensuring that tariffs allow suppliers to improve consumer participation in

demand response, depending on national circumstances.

The Energy Efficiency Directive was therefore the first Directive to define consumer rights for participation within the energy markets. These principles have been built upon in the following Directives and Network Codes.

The Internal Market-legislation [4] further develops common rules for the internal electricity market, which include:

- Market design shall encourage competition – also between differing resources, including demand side resources.
- 80% of the consumers shall be equipped with intelligent metering systems by 2020 (where roll-out was assessed positively).
- Member States shall ensure that customers are entitled to receive all relevant consumption data, enabling them e.g. to improve efficiency and to participate in demand response programs[5].

Network Codes: One of the objectives of the ENTSO-E Network Code on Electricity Balancing is to facilitate participation of Demand Side Flexibility including aggregation facilities and energy storage supporting the achievement of the EU's targets for penetration of renewable generation. The Codes have been critical for the deployment of Demand Response as they take the principles outlined in the Energy Efficiency Directive and incorporate them into the full set of Codes used by TSOs across Europe for their cross-border balancing services. National TSOs use these as the basis for their own

[4] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC

[5] Also, related to metering, the Commission has issued on 9 March 2012 a recommendation on preparations for the roll-out of smart metering systems (2012/148/EU). It describes the minimum functional requirements for the smart metering system including: 1) Provide readings directly to the customer and any third party designated by the consumer by provision of standardised interfaces for energy management solutions in 'real time' for DR services etc. 2) Update the readings frequently enough (every 15 minutes) as a general rule. 3) Smart metering systems should include advanced tariff structures, time-of-use registers etc. to achieve energy efficiencies and reduce the peaks in energy demand. ' (Vito 2016)

national codes as well. In their current form (at date of writing not all Codes are finalized), they include the requirements for grid connections, participation in balancing markets, communication and security provisions for demand facilities, and establish a common framework for connection agreements between the demand facility owner or the distribution system operator vis-à-vis the transmission system operators.

Energy Performance of Buildings Directive 2010/31/EU (EPBD) replaces Directive 2002/91/EC and defines a more ambitious framework to improve the energy efficiency of EU buildings in the light of the experience gained and progress made during the application. The Directive outlines the need for connectivity between buildings and the grid (smart, flexible buildings) in order to promote the efficiency of the system and the integration of intermittent renewables.

Appliances are the key for empowering residential and SME consumers to participate fully in the energy transition. The **Ecodesign** and **Energy Labelling Directives** are the core pieces in a comprehensive set of initiatives governing the energy markets and networks as a whole and provide guidance for the supply and demand side of smart and energy efficient appliances.

The Ecodesign Directive sets out standards for the energy efficiency of products. Ecodesign "*contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply*"[6]. The Ecodesign Directive sets the framework defining the "rules" for setting mandatory requirements to improve the environmental impact of products. The requirements are established in implementing measures (regulations) or, alternatively, voluntary agreements. **The Energy Labelling Directive** creates standards for labelling, helping consumers identify products with high environmental performance. It creates the framework defining the "rules" for setting product-specific requirements and legislation on standardized information regarding the consumption of energy, water and other resources.

Timeliness of this study

Therefore, for the first time, there is now a set of Codes, Directives and Communications, covering the full value chain, from energy market design to appliance labelling, which support the participation of demand side resources in the energy markets, through smart

[6] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products, Article 1.

appliances and other technologies. This adds relevance to a study covering the potential costs and benefits of these capabilities. The study covers the full range of smart appliance enabled programs, including energy efficiency, Implicit Demand Response (IDR) in the form of Real-Time Pricing and Critical Peak Pricing, and Explicit Demand Response (EDR), i.e. balancing and ancillary services for TSOs.

1.3 The wider business context

This study provides a carefully quantified analysis of the costs and benefits of energy related services in the form of Demand Side Flexibility (DSF) through smart appliances. However, early anecdotal evidence suggests that demand side flexibility and improved energy controls are often not sold alone, rather they are sold within a large Smart Home package as part of a wider set of services. By necessity therefore, this study is incomplete as both the costs and benefits are centred on energy management and energy efficiency but in reality, these capabilities may well be sold to the consumer as part of a service package; a package which may include security services, health services, general home automation services, information and connectivity services, etc.

Indeed, today machines are able to communicate with each other, with their owners and also to receive and send messages to the outside world. This is all done in coordination with the movement of the sun, wind, or the stock market, or a patient's state of health, a security concern, the owners expected schedule and so on. The capabilities do not stop with energy management.

However, the value of energy management is relatively 'easy' to quantify and measuring it also plays into an industry culture which is used to thinking of itself as autonomous: a public utility providing the must-have service of electrification. However, if industry trends continue, this autonomy may be farther and farther from reality. On top of a natural increase in energy independence among home owners, utilities are competing in a crowded smart home industry: security firms, IT giants such as Google and Apple as well as health and human service providers are all already in the space and have a wealth of experience in customer service and business development.

Due to the important legislative effort behind the development of smart home and consumer access to energy related services as well as the significant potential benefits energy management and savings can bring to society, it is non-the-less relevant to understand the potential value of the energy component of a smart home. That said, this study neither reflects the likely value chain within the market or the full value of the product, nor the full range of products and services available. Rather it carefully quantifies the value of smart appliance enabled energy savings and energy management services as well as their benefits to the wider society.

Section 2: Study Definitions and Methodology

Section 2, provides a discussion of key terms and three descriptive User Stories meant to illustrate how and why consumers engage in smart appliance related programs. Finally, the study's mathematical methodology and key assumptions are explained.

2.1 Definitions of key terms

Below are relevant definitions to the study. A full list of key terms can be found in Annex I. For the purpose of this cost benefit analysis, we use the definition of a smart appliance found in the European Commission preparatory study for eco-design.[7]

Smart appliances: '*This is defined as an appliance that supports Demand Side Flexibility (DSF):*

- *It is an appliance that is able to automatically respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);*
- *The response is a change of the appliance's electricity consumption pattern. These changes to the consumption pattern are what we call the 'flexibility' of the smart appliance; Whereby:*
- *The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point in time by the consumer or a service provider'.*

The **flexibility potential** of a group of appliances is defined by two parameters:

- *'A shifting potential = amount of energy that can be shifted, expressed in [MWh/h].*
- *Average maximal shifting period = average maximum number of hours [h] that appliance can be shifted (i.e., to consume later/earlier in time than initially planned)'*

Smart appliances may include all controllable devices within a home, which consume electricity (or gas), such as heating, cooling, hot water boilers, ventilation systems, dishwashers, fridges, freezers, dryers etc.

Demand side flexibility programs included

[7] Vito (2016)

Smart home technologies enable a range of energy saving and energy management services. Today, demand side resources (including household consumers) are participating successfully in the full range of energy markets from the wholesale market, where prices are known the day before, to the frequency services, which require second by second controls.

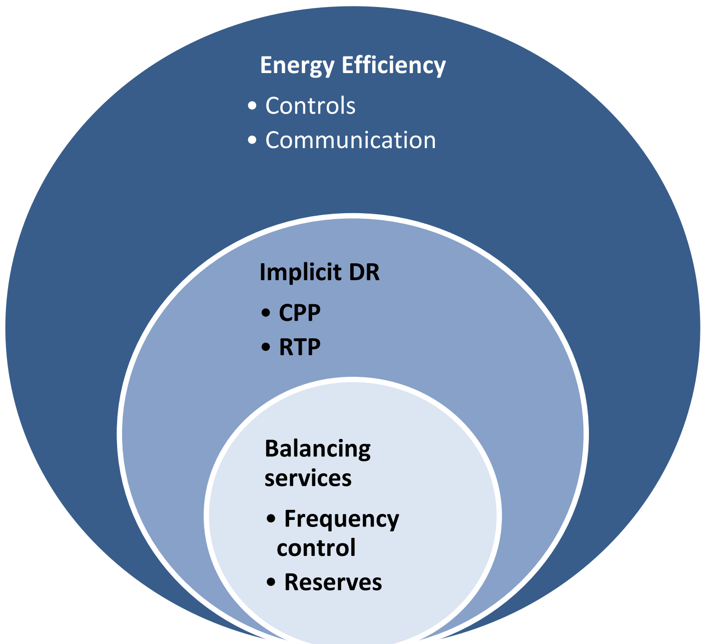

Figure 1: Types of demand side flexibility included

Below is a short description of the demand side flexibility programs covered. They include automated energy efficiency through improved controls, the Implicit Demand Response programs, Real Time Pricing (RTP) and Critical Peak Pricing (CPP), and services sold to the TSO to lower the cost of balancing. These explicit DR programs are those covered in the Network Codes: tertiary reserve, secondary reserve, primary reserve and for the UK, the triad program.

Automated Energy Efficiency (consumption optimization): With the support of smart appliances – home automation, control and information are combined to lower the total consumption of the home or to optimise energy usage. The intelligence provided by the systems increases awareness but also enables sustainable choices. It is the difference between trying to remember to turn down the heat before going away for the weekend and having the central heating and hot water turned down every time the occupants are absent, e.g. every time they are at work. These same controls then warm the building again before they return. In cold climates, improved control and automation is critical – it is highly unpleasant to return cold home after work. In this case, having the ability to both lower and raise the temperature remotely makes energy saving choices possible. Smart home automation and smart appliances have shown to significantly increase the impact of energy efficiency programs in households. While reductions through feedback alone tend to be between 0% and 10% with home automation this is increased to 15-25%, particularly in homes with heating or cooling. (An average of 15% for high consumption homes is used in this study, while low consuming homes are modelled as reducing total consumption by 5%).

Demand reduction therefore may involve a combination of an informed set of choices ('behavioural change'), and the smart home controls – which allows these behavioural choices to be maintained over time; for example consistently turning down the thermostat when the building is unoccupied, or automatically running the dishwasher on the eco-cycle.

This same set of controls can also be used to allow prosumers, with solar PV on their roves for example, to better coordinate their consumption with their generation capabilities. If self-consumption is legal within national regulation, this can strongly reduce the pay-back time of the initial PV investment.

Demand Side Flexibility (DSF): Yet again the same infrastructure enables consumers to effectively participate in the different forms of flexibility programs available, including implicit and explicit demand response, depending on a viable regulatory framework and assuming that they have retailers or aggregators who offer them the necessary service. It is important to note that neither form of Demand Response is a replacement for the other.

Implicit Demand Response (IDR) (sometimes called "price-based demand response") refers to consumers choosing time-varying electricity prices or time-varying network tariffs (or both) that reflect the value or cost of electricity and/or transportation in different time periods and the consumer's decision to react to these price differences, depending on their own initiative without a defined requirement to react. These prices are part of their supply contract and usually coordinated with the spot market.

Within this study, two types of market based IDR have been included, Critical Peak Pricing (CPP), and Real Time Pricing (RTP). Static forms of IDR – such as Time of Use pricing (ToU) have not been included. They can have a harmful impact on total systems efficiency in situations where intermittent renewable generation is present; its use can increase pollution, balancing costs and network constraints. These are therefore not considered future proof programs. Rather, the report focuses on the two forms of IDR which are relevant and useful in a future oriented high renewables context, when the widespread use of smart appliances technologies is expected to become ubiquitous.

Critical Peak Pricing (CPP) are day-ahead programs, usually developed for both residential and commercial consumers. They involve raising prices or offering financial incentives to cut demand for a set number of hours on days when critical peaks in consumption are expected, usually due to exceptionally hot or cold weather. Both the numbers of days on which a peak can be called and the number of hours are known beforehand and usually regulated at a regional or national level. By their nature, they occur at irregular intervals in either winter **or** summer and come under the heading of dynamic peak shifting.

Real Time Pricing (RTP)

This type of programme is the most closely aligned with situations where supply as well as demand are variable or 'unbiddable', meaning that a significant portion of national capacity is sourced from intermittent renewable generation. RTP is a means by which retail prices follow wholesale prices from day to day, hour to hour or even minute by minute. Spot pricing can be linked with automation to lower demand whenever wholesale market prices go over a certain pre-set amount.

Taking advantage of RTP to shift consumption is almost impossible without smart appliances and smart home controls. These controls significantly increase consumer response as appliances such as hot water heaters, air conditioning or fridges can turn up and down without the customer even being aware of the changes. Indeed, in pilots without controls a consumer's response is usually 0% (no response) while with controls responses of between 10% and 35% are seen.

<u>NOTE:</u> Unlike other dynamic pricing programs, consumers almost always save money over 3 – 5 years on an RTP programme with or without shifting consumption. This is due to the fact that the customer has accepted the short-term risk of variable pricing. They therefore do not pay the risk premium the retailer must charge for keeping prices flat. With flat retail prices, the retailer takes the risk of variable prices and charges extra to hedge this risk – the customer therefore pays the real cost of the electricity, the retailers profit margin and the hedge against price fluctuations. With RTP, the cost of this hedge is removed – and the customer's total electricity costs are reduced. Therefore, RTP makes economic sense (with or without automation) unless a consumer has strong

economic constraints and cannot accept that their electricity cost will vary slightly between years.

Explicit Demand Response (EDR)

EDR is the type of demand response referred to in Article 15 of the Energy Efficiency Directive. In these programs, demand competes directly with supply in the wholesale, balancing and ancillary services markets through the services of aggregators or single large consumers. This is achieved through the control of aggregated changes in load traded in electricity markets, providing a comparable resource to generation, and receiving comparable prices. This means those running the programme have an obligation to react as contracted. Therefore, while a household consumer may not be aware of the fact, the aggregation service provider will be obliged to deliver the savings as bid and contracted.

Due to the fact that this is a contracted service, consumers receive direct payments to change their consumption upon request (i.e., consuming more or less). Consumers can therefore earn from their flexibility in electricity consumption individually or by contracting with an aggregator. The latter can either be a third-party aggregator or the customer’s retailer.

In this study, we include the range of balancing mechanisms described within the TSO Network Codes. These include: tertiary reserve, secondary reserve, primary reserve and for the UK, the TNUoS fees, commonly known as “Triads” programme.

2.2 User Stories

Below are descriptions of three user stories, which capture the types of programs and economic values modelled within the study. They also look to capture the ways in which consumers often understand the programs they participate in. This understanding can differ significantly from the industry’s understanding.

A. Smart meter rollout, dynamic pricing, control

Grace and Steve live with their 3 children in an apartment building containing 6 flats, in Helsinki, Finland. They have a smart meter and can track their hourly energy consumption online. They have checked it once and thought it was interesting that they consumed so much while they were away or asleep. The owner had recently purchased new appliances for their apartment, including a dishwasher, a dryer, a fridge and a washing machine. The building has centralised heating and ventilation.

About 6 months in to their lease, they get a note from the building manager stating that they have an offer to improve their feedback information but also to put their appliances and the centralised building units into a 'renewables friendly dynamic pricing program'. They actually have no idea what that means but apparently, it is something to do with using more when there is a lot of wind generation in the system and less when generation comes from gas, coal or nuclear. They hate the politically unpopular Fennovoima nuclear plant and are happy to consume less electricity from them.

They tick the box yes – they agree to participate.

Their retailer, Helsinki Energy comes and shows them how their already purchased appliances are controllable (they actually hadn't noticed but it is apparently standard these days). They help them install the programme in their phones.

Result: Sometimes their dishwasher or dryer delays starting during the day and they have heard the ventilation fan go up and down. Steve has overridden the washing machine programme a few times when they needed clothes done for work and school. Meanwhile, their energy bills have been reduced by a small amount – but in reality, they can't notice the difference. However, they like the reports they get letting them know of the part they play in supporting Finland's wind generation – a cleaner future for their children. Overall, it's a good thing, and most of the time, they forget they are participating in any programme at all.

B. Energy savings and demand response

Father John lives in an alpine town in France, his parish is spread over several villages and towns in a large surrounding area and he spends a good portion of each week driving and away from home at irregular hours. He has bought an old farmhouse, and has renovated the kitchen but overall the efficiency of the building is poor. However, his main concern is not energy but security. He is concerned that while he is away on one of his many trips, he will suffer a break-in. He therefore has bought a security package. The package happens to include 'energy management' services. He didn't pay attention to these while making the purchasing decision but thought it might be nice to keep track of his ancient boiler.

The security company arrives and not only installs an alarm system and security camera but also ensures that his appliances are communicating with an app they help him download to his phone. They explain that he will now be able to remotely control his heat and indoor temperature. They also help him adjust his settings so that when he is away, the hot water boiler, heating, lights and all other appliances will be turned either down or off. The systems will improve his security and also lower the total energy consumption of his home. He will also receive an alarm, both if someone breaks in but also if his boiler – which is dying any day now – finally goes.

The security company also asks if he would like to have his appliances participate in a dynamic pricing programme (react to price fluctuations on the spot market) and a set of demand response programs. They say that his hot water heater will react to price signals and that he can just leave his dishwasher on standby and it will run when electricity costs are low. They also mention something about 'frequency response' – Father John doesn't bother learning what that is but in any case, he gets paid a little by someone called RTE. It sounds fine.

Result: It is Father John's first winter, so far no one has tried to rob his house but his energy bills have been reduced by 31%! He didn't realise how often he was forgetting to turn down the heat when away. He also notices that the security company is adding small amounts to his account for the demand response programs his home is in. Also, his boiler did indeed stop twice while he was away, but thankfully the alarm went off and he was able to have a neighbour go in and re-start it. He really will need to buy a new one next winter. His security firm says that when he does this – he'll pay even less in energy bills and also his demand response payments will increase. It sounds good. The security service still costs him more than what he saves on his energy bills – but now that he has the services, they really are a valuable part of what he is buying!

C. Self-sufficiency: SME business development

Lucia lives in Tellaro, Italy on the Mediterranean coast near the hiking trail that goes to Lerici, a popular track for tourist and also residents. It would be a beautiful place to sit and have a glass of wine with a piece of fresh focaccia and look out over the olive groves down to the sea. Her family owns a small olive grove and also one of the old stone barns that used to house the equipment and couple of animals but now stand empty. Lucia and her husband have been unemployed now for 4 years, they either need to find work locally or sell her family property and move.

Lucia therefore wants to renovate the old stone barn and open a little café for hikers. Her husband and his uncle are good at construction but the utilities are an issue. She can pay for water but she wants to try and avoid the electricity and gas costs as much as possible.

Lucia's uncle knows a contracting firm specialised in supporting those going partially off-grid. It will mean upfront investment in solar panels and batteries, but it will also mean that all her appliances need to work in unison and be prioritised. She also needs to be aware of her energy resources at all times, if her battery set is running low etc.

When the premises are ready, the PV and energy management firm arrives, they install the panels, batteries and an emergency generator. They also ensure that all appliances are coordinated to use as little capacity and electricity as possible. Through her phone, Lucia has full oversight and control at all times of every appliance on the premises, she can even control the fridge for short times. In the end, she decided to take a loan to pay for the PV panels. However, these payments are steady and known in advance, and after this period she will no longer have significant utility bills, improving the return of her small business.

Result: The small terrace in the olive grove is ready, the focaccia bought from Luca the baker and the wine is chilled. Tourist season is here. Lucia is ready for her new career and happy not to have to worry about every increasing gas and electricity bills. What a thought!

These are consumer stories – and they point to important requirements for success, which have been researched in consumer centric projects such as ADVANCED and also reflect the market experience of those working with customers.

1) Core interest: Consumers often buy something other than energy efficiency when signing up to a programme. They may purchase independence, a vote for their children's future, security, style or any number of other drivers rather than energy efficiency, system's efficiency or even financial savings.

2) Trust: Programs must be sold by a trusted source, particularly when home automation is concerned. For example, here Grace and Steve are purchasing from Helsinki Energy, a small, active and local retailer. Father John is purchasing from his security firm and Lucia and her husband are buying form a local contractor.

3) Convenience: All three examples require no work to maintain and almost no inconvenience at all – in fact the consumers are able to forget they are on them and receive the same benefit (except for Lucia off-grid).

4) Understanding: The customer needs to understand the parts that are important to them, and they have the right to full information access, particularly their energy and financial savings or earnings. However, many times customers are not interested in the details concerning their programs (for example, what is a balancing market?) and full understanding should not be required for success.

5) Control: Customers must always maintain final control. The override function is key to building trust and avoiding such a high level of irritation that the customer quits the programme.

If any of these 5 core elements are missing, maintained success is unlikely.

2.3 Methodology

As mentioned above – this study concentrates on the costs and benefits of the demand side flexibility and savings capabilities of smart appliances. As such the costs as well as the benefits are placed on a few technologies, which may in reality be part of a larger service package. Residential consumer load is low in comparison to commercial or industrial (C&I) customers, and as a result the size of loads under control are small and the cost of the technology required is often seen as a deterrent. Consequently, the scale of reward compared to the effort per customer and cost of installing a system may be seen as inadequate. The reward may also be further eroded by the complexity of the transaction. While transactions are at least as complicated for C&I customers, they bring a higher individual return and therefore provide a clearer business model. In the residential space, the returns for an individual consumer are lower and therefore any complexity or costs have a higher impact on the total business case.

Aggregation, holistic business models and appropriate regulation are therefore all key enablers. One conclusion can be that the residential market is often seen as too fragmented to be a viable demand side flexibility resource. However, this is to ignore the fact that residential demand is a significant portion of total national demand and an even higher portion of national peak demand: in 2012 in the UK the residential sector made up 33% of the total electricity power demanded and 60% of peaking consumption. In addition, its peak profile is different to that of industry and therefore the two are complementary. The challenge is to find ways of enabling this demand-side resource to be accessed.

The study thus comprises a cost-benefit analysis for Demand Side Flexibility (DSF) value chain, of the introduction of residential DSF. The sensitivity analysis takes into account the current market prices for each country (including the wholesale market clearing costs) in the intra-day, balancing and the ancillary services markets, and the key success requirements for the market actors for a positive business outcome. The consumer flexibility is based on the VaasaETT database of 140 pilots to extract the potential of DSF in a first phase and on the E-SSET energy asset valuation tool, supported by Joule Assets, to perform the cost-benefit analysis for 4 Member States EU countries and one best case representative country.

The cost-benefit analysis is provided per consumer segment, per program, per EU country. All of the values are calculated against actual and current market data and market structures. This was done with the exception of the Italian Balancing market which is currently opaque and where no open competitive market exists. Here the French balancing market structures and prices are used but with the Italian consumer information.

The results therefore are NOT scenarios but actual results, which could be earned today assuming markets were open to consumer load and smart appliances and accompanying programs were ubiquitous.

The results thus provide clear quantification of the cost and financial benefits of residential DSF and clear recommendations how to facilitate the roll out of residential DSF solutions in Europe.

This section describes the methodology used to calculate the financial costs and the benefits of smart appliances for small consumers taking part in energy efficiency, and Implicit and Explicit Demand Response programs.

Source of pilot and consumer behaviour data

VaasaETT keeps an up-to-date database consisting of, at the time of writing, close to 140 EE and DR programs around the world, including 569 samples, and involving over

930,000 residential customers. 42% of the samples in the database come from US pilots, 28% from Canadian ones, 23% from pilots that have taken place in Europe, 6% in Australia and 1% in Japan. The database compiles the findings of both feedback and dynamic pricing programs with and without appliance automation.

The VaasaETT database is the largest of its kind. It is able to provide statistically robust quantified answers to questions related to the potential of demand flexibility programs to reduce various types of customers' bills, consumption levels and/or to manage consumption in time and hence regularly constitutes the building block of simulation and modelling exercises. The database was recently used in projects conducted for the European commission (e.g. FP7 ADVANCED, FP7 eBADGE, H2020 NatConsumers), the Norwegian water and energy regulator NVE, ESMIG, BEAMA and others.

To answer the research question, the following information was extracted from the database:

- Change in overall consumption (% kWh);
- Change in consumption during peak hours (% kW).

Energy efficiency results (%kWh):

- Direct feedback programmes (no automation, no dynamic pricing),
    - Overall consumption reduction: 7.00%, 195,774 participants, 126 samples.
- Pricing programmes with automation for the purposes of peak clipping (+ feedback to support peak clipping)
    - 2,68%, 25,495 participants, 30 samples.
- Energy efficiency with automation for the purpose of lowering total consumption, (with feedback included)
    - 16.75%, 10,168 participants, 5 samples
        - (Used as the basis of the energy efficiency modelling, for example in Section 3.2)

Peak consumption reduction results (kW)

- RTP with automation
    - Peak reduction: 11.25%, 281 participants, 4 samples. (Small sample size).
- CPP with automation,
    - Peak reduction: 33.66%, 13,201 participants, 33 samples.

For this study, we have divided the consumer data into high-, medium- and low-consuming households. These categories match the regulatory standard of each country.

Quantification of Implicit Demand Response benefits

Source of market pricing data: The modelling began by analysing the existing data sets available in each Member State covered.

Consumption data: For France, consumption data focuses on hourly national load data split into sectoral categories - residential, tertiary, industry, other. The data set was sourced through the RTE Open Data platform [8]. The set is described as follows: "*Baseline scenario for [the] 2015 generation adequacy report (within continental France): Model of average power requirements (MW) per hour and by sector*/use by 2019-2020, based on calendar template for 2006-2007…".* Based on this data, the share of residential load was calculated for every hour of the year and the average share of residential load for every month-hour (e.g. the average share of residential load every time it was 19 o'clock in November) was calculated for each month. For the UK, Germany and Italy the share of residential demand in total demand is taken as a fixed number based on information provided by VaasaETT[9].

Pricing data: The first set of pricing data is the 500 hours with the highest wholesale day-ahead market price. The markets used were the EPEX spot for France and Germany, the N2X for the UK, and the GME for Italy.

Load information: The second data set is the national load information corresponding to these top 500 hours from the ENTSO-E data platform[10].

Investment payback times: The payback times are compared to those of some forms of generation and energy efficiency technologies. The information for these comparisons

[8] Page: https://opendata.rte-france.com/explore/dataset/bp_2015_scenario_conso_horaire_brute/. Found September 2016

[9] -France: RTE (2015) -Germany: BDEW (2015) -UK: Digest of UK Energy Statistics (2016) -Italy: AEEGSI (2015)

[10] https://www.entsoe.eu/db-query/consumption/mhlv-a-specific-country-for-a-specific-day Found September 2016

is internal company knowledge gathered by Joule Assets during their investment activities.

For the **RTP Programmes**: The average share of residential load was plotted against the exact month and hour in each of the top 500 hours with the highest price. Similarly, national load data was plotted against the top 500 hours with the highest price. Then, the amount of residential load at every fop 500 hour was calculated as the product of the average share of residential load at that month-hour and the national load at that date-hour.

Following this, we calculated the ratio of the three customer groups in the residential load. This was done starting from the estimated yearly consumption for each group, and the estimated percentage of total customers belonging to each group provided by VaasaETT data base of consumer information and pilots. Building upon this, each group's share in total number of households and yearly consumption were multiplied with the total number of households per country (found from the Smart Appliances Study Task 6).

The result was the ratio of each customer group in the yearly consumption. Based on this, it was assumed that these would also be the ratios of each customer group in the residential load at any given time. Following this, the amount of residential load was multiplied with that each customer group share to calculate the amount of load each group is responsible for at any given hour.

Each customer's load amount was then multiplied by its flexibility percentage and uptake rate. The flexibility capabilities were provided by VaasaETT, and only the automation pilots were taken into account. The uptake rate of consumers was assumed to be 30% for every country, meaning that 30% of national residential consumers were assumed to participate in at least one programme type. The result of this calculation was the amount of load reduction for each customer group at any given hour. This number was then multiplied with the wholesale market price at the corresponding hour to calculate the value of load reduction for every customer group and for the total reduction. Each reduction is assumed to last 1 hour.

The rebound rate is assumed to be 60%, and the rebound occurs in the three hours after the initial reduction. However, if the last rebound hour taken into account was hour 24, it was assumed that no rebound happens after this hour. The hourly price of rebound was taken as the average wholesale price between hours 21 – 24 for the whole year. We have used this calculation in order to avoid the reverse pricing effect that would sometimes happen when simply taking the wholesale price at the exact date and hour for the identified rebound hours. This reverse effect occurs when the wholesale market price in the rebound hours would sometimes be higher than the price during the load reduction hour, resulting in inflated rebound costs. It is assumed that customers would usually rebound their consumption in hours of lower prices than the original event. The average price between hours 21 and 24 (when most of the rebound happens) is usually lower than the pricing during the reduction hours, and in part reduces the reverse effect.

For CPP, the top 500 hours were rearranged according to the highest load at any hour, and out of those top 30 hours were taken. For each of those, the corresponding load reduction was found according to the previous RTP calculation. The load reduction was multiplied by the energy part of the price provided by VaasaETT[11] and the CPP ratio of four. This was the calculation for the value of load reduction.

The cost of rebound was calculated as a simple product of the 60% of the initial reduction and the energy part of the price. The load reduction also lasts 1 hour in this case, for comparability with RTP data. These assumptions take a lower rate of rebound for heating systems and a higher rate (close to 100%) for smart appliances such as washing machines and dishwashers into account. Note that applying a rebound effect of 85% had an insignificant effect on the overall results.

In both RTP and CPP, the net benefit is calculated as the value of load reduction minus the cost of rebound. Additionally, we have assumed a 3% discount on the energy part of the utility bill for customers participating in implicit DR programs.

Explicit Demand Response

The modelling of EDR potentials was based on the same assumptions as for the IDR potentials. However, only 10% of the total flexible residential capacity per country was included in the calculation. (This is to account for any discrepancy in response to EDR calls). A 24/7 availability and either 100, 200 or 300 hours of activation per year were assumed, depending on the type of reserve.

In balancing reserves, there are currently requirements in place, which in reality block residential DSF from participating. Minimum bid sizes, notification times, activation methods and contractual arrangements with BRPs are only some of the many barriers in

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[11] Household Energy Price Index by Energie-Control Austria, MEKH and VaasaETT Ltd (2016)

place. As a consequence, no participation is currently possible in any of the programs in Germany or Italy, while in France residential consumer participation is possible in reality only through the retailer, as consumers must pay prohibitive fees if they contract with an aggregator. In the UK, participation requirements change often and tend to favour generation assets.

Conditions: In order to perform the cost-benefit analysis, this study assumes these barriers are removed and residential consumers have access to markets on equitable terms at current market values. Therefore, in France, Germany and the UK actual market structures and prices are used. In Italy, there is no competitive balancing market and prices are not public. Hence, the French balancing market structure and pricing were used, as France is also closely following the development of the network codes and has significant experience with demand response.

The reference country "consists" of the best possible conditions found in the other 4 countries: Reserve market values from Germany and flexibility potentials from France.

Energy efficiency benefits

Energy efficiency savings are calculated based on VaasaETT sources on savings from energy efficiency pilots using automation (rather than feedback or other forms of information only). A yearly energy bill is calculated for each customer group in each country, with prices and energy consumption. We assumed 15% savings from automated energy efficiency for high-consumption households, 8% for medium- and 5% for low-consumption households. The yearly consumption costs for each customer group were then multiplied with the savings percentage from the pilot results to calculate the savings. Hours when customers participated in either an RTP or CPP event were deduced from the total hours when they achieved EE savings.

Costs

To calculate the costs, a set of smart appliances and required devices for each customer group was defined. The table below provides an overview of costs for gateways and displays as well as the marginal costs for making household appliances "smart":

Energy Management Gateway	75€
In-home display	55€
Dishwashers	10€
Washing machines	10€

Tumble dryers	10€
Refrigerators	10€
Electric heating	10€
Electric boiler	10€

Added costs to enable smart appliances (in € per household):

High consuming	€ 190
Medium consuming	€ 170
Low consuming	€ 160

Costs to enable these appliances to participate in DSF were gathered from the study's clients, and from the eco-smart appliances report Task 4 – Technologies, Technical Analyses of Existing Products[12]. Further, we defined the number of eligible households participating in DSF. We assumed an uptake rate of 30% as in the DSF revenue calculation, and multiplied it with the total number of households in all the countries.

Households were split into three customer groups, and the number of households was multiplied in each group with the respective costs, which were described above and shown in the Cost Assumptions table. The final results are the technology cost of enabling 30% of households in a country to participate in DSF.

Other significant costs related to the programme rollout itself, for example marketing costs, personnel training, salaries, are not included here, as these are too individual per provider and also combined with a range of capabilities and costs already in these business entities. Offering a smart home programme could potentially be highly expensive to a provider or cost little, depending on the capabilities they already have in-house.

Appliances per customer group

[12] http://www.eco-smartappliances.eu/Documents/Prep%20Study%20Smart%20appliances_Task%204_160504.pdf) September 2016

High consuming	All devices above
Medium consuming	No dryers and electric heating
Low consuming	No boiler, dryers and electric heating

Societal Benefits

Additional DSF capacity clips peaks, resulting in lower clearing prices on the spot market and having a long-term price effect for the whole market by reducing the risk premium in power future markets. The effect of lower clearing prices is a benefit to all market participants and is here considered a "societal" benefit.

EXAMPLE:

France, on February 4th 2015, at 18:00:
EPEX SPOT price: **77 €/MWh** National load: **83 GW** SPOT market volume: **15 GW**

→ Modelling the impact of 1GW of Demand Reduction on market prices:

The average market price at 82GW (in other words, 1 GW below the actual demand at this hour) of national load in the rest of winter: **61 €/MWh**
We then assume a price reduction due to the reduction by 1GW, hence we calculate with the average price at 82 GW, instead of the price at 83 GW. The difference is significant: 77€ - 61€ = **16 €/MWh**
Benefits are then calculated assuming the reduction impact:

On the spot market:
16€/MWh x 15GWh = 0.24M€

On the whole market:
16€/MWh x 82 GWh = 1.3M€

The benefits are calculated as in the other cases with a 60% rebound over the next 3 hours, and for the TOP 500 hours per winter.

Societal benefits, created by lowered whole market trading costs, have been quantified by RTE and RAP [13] independently. They are also part of FERCs (Federal Energy

[13] Baker Phil, 'Benefiting Customers While Compensating Suppliers: Getting Supplier Compensation Right' Regulatory Assistance Project, 2016 AND, RTE "Expérimentation sur la valorisation des effacements de consommation sur les marchés de l'énergie (dispositif "NEBEF 1")." Retrieved from http://www.rte- france.com/uploads/media/pdf_zip/alaune/2013_10_16_ NEBEF_Rapport_de_consultation_Vdiff.pdf

Regulatory Commission) calculations for the benefits of DR in the USA. When prices no longer go above a certain price threshold – traders no longer have to hedge above this price. The entire cost of the market is therefore reduced. This has a significant impact on the cost of a particular hour of electricity, for example, if the average MWh price is reduced €1 – and 1,000 MW are traded that hour – the whole market saving is €1,000 for that hour. This creates a robust societal benefit from demand side flexibility in lowered costs for electricity. These benefit all consumers, both those on and off the programs.

The ratio of benefit per MW of DSF to societal benefits through the reductions in the whole market clearing costs, is getting smaller with every MW added – the impact of DSF per MW is therefore reduced, as the peaks are already clipped and there is less impact on the price. This tendency is taken into account in these calculations.

Section 3: Cost Benefit Analysis Results

Below is a description of the cost-benefit analysis of smart appliances and its main results within demand side flexibility programs. It begins with the specific national and consumer findings and progresses to the total cost versus benefits. Three key elements were quantified: financial costs and earnings, electricity energy savings (MWhs) and electricity capacity reductions (MW). The findings are ordered as follows: the value of DSF alone, against costs and with and without societal benefits; the value of energy efficiency through home optimisation, the value of all programme forms against costs. The potential of smart appliances to create energy savings and to create flexible capacity with their respective pay-back times.

3.1 Results: Demand Side Flexibility

Smart appliances allow residential consumers to participate in the energy markets through selling their demand side flexibility as a resource and either saving money or receiving direct payment. While these programs can provide good monetary value to single industrial/commercial consumers, due to the large volumes of electricity consumed at a single site, for residential consumers the programs are rarely valued on energy price fluctuations alone, rather the valuation and payments are based on three elements:

1) energy price fluctuations
2) network capacity issues and improved efficiency
3) lower cost of balancing for the retailer.

These tend to be the three drivers for establishing Implicit Demand Response programs on the part of the utilities that offer them. As such, the offering is bundled with the retail price and the value of the shifted load is not separated out or rather not transparent to the consumer.

Critical Peak Pricing (CPP): In a CPP programme where the retailer sets the price ratios, the offering is often combined with the value of network constraints. For example the French Tempo tariff combined all three value streams above when paying customers, avoided network fees, balancing costs and peak shifting away from high price hours. Today, when it is no longer (as) legal for the network operator and the retailer to cooperate, EDF is no longer actively promoting this tariff.

The figures below represent the value of peak shifting and the accompanying lower electricity price, without quantifying any possible payments to the consumer for their flexibility from the network companies.[14].

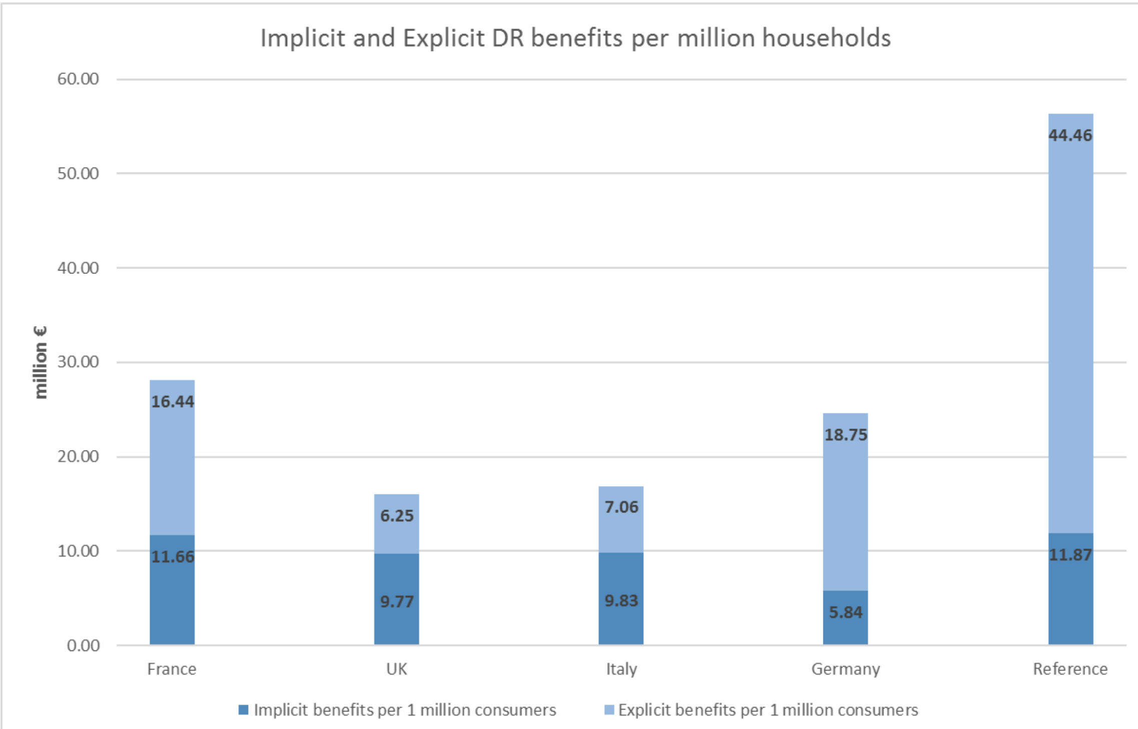


Figure 2: The annual value of IDR & EDR per million households

Payments for Explicit Demand Response (EDR) allow a customer to sell their flexibility as a service to the TSO within the balancing markets. The prices paid for these services are usually significantly higher per hour than shifting flexibility within an Implicit Demand Response (IDR) programme (prices based on wholesale market fluctuations), however consumers participate fewer hours per year in an EDR programs and therefore the total value in one programme type compared to another may vary depending on Member State and year.

Participation in balancing markets is also more costly and this may remove any added payments – depending on the rules set by the national TSO. Indeed, unless balancing

[14] Though on a national level reduction in overall network investment through demand response have been modelled to be significant, they may be low per household. In the H2020 Project ADVANCED DSO networks were modelled and the possible value of between €1.20 and €3.00 per house per year. 'D6.3 Economic Benefits of AD for Stakeholders'

markets are designed in a manner, which specifically aims to allow small consumers and renewables to participate, ubiquitous programme rollout is unrealistic. This may develop in the future, for example in the French mFRR (Fast Frequency Response) market, a statistical model for participation will begin to be used for the first time. This would allow aggregators to bid small loads from, for example, fridges and freezers that may or may not be running at any given time.

France provides the best results for both EDR and IDR. This is due to its weather-related price peaks within the wholesale markets as well as high prices within the balancing markets (making both forms of demand response relatively valuable for participants). An increasing portion of French households use electric heating, on cold days this drives up the cost of electricity and forces EDF to import extra capacity.

The **UK** has relatively low and stable wholesale market prices as well as relatively low balancing market costs.

Italy's wholesale market prices, impacting the value of IDR, are flat in comparison to those of France. At the same time the prices on the balancing market are set through non-public bi-lateral agreements between the TSO and generators. Therefore, the market is not open to competition and real prices are unknown (French prices were used here against Italian consumer data).

In **Germany**, wholesale market prices are depressed due to the large influx of subsidized renewable assets and no longer fully reflect the value of capacity. This accounts for the low value of IDR programs in Germany relative to the higher value of EDR – which participates in the balancing markets, where competition is still minimal from demand side units.

Reference Country: The driving factor for the increased benefits in the reference country, are the combination of Germany's balancing service payments with France's consumption levels. Ubiquitous device rollout and strong competitive markets, are again key.

Current market status: Today residential consumer participation in balancing markets is either impossible or difficult in all Member States:

- **France:** Residential consumers may participate through an aggregator or retailer, however in reality regulatory requirements, such as the requirement to pay for the retailers' losses and other barriers such as the number of hours during which a consumer can be activated if they are working with an aggregator (rather than a retailer – in which case there are no limits) cause issues. However, with time these may be removed.

- **Germany:** Residential consumer participation is impossible. Not only do most consumers have no smart meters installed, but balancing market rules are prohibitive even for industrial consumers. The German government is considering important changes to the current regulations which block market growth for demand response and this situation may improve in 2018-19.
- **Italy:** In Italy, dynamic pricing is not available to enable IDR and no consumer (industrial, commercial or residential), no matter their size or capabilities is able to compete in the balancing markets through EDR.
- **UK:** In the UK, residential consumers have access to dynamic prices and may also participate in the balancing markets to a limited degree but on a commercial basis (no longer pilots only). Usually this is done through small independent retailers who use the consumer's DSF to lower or control their own balancing costs and improve the consumer's comfort.

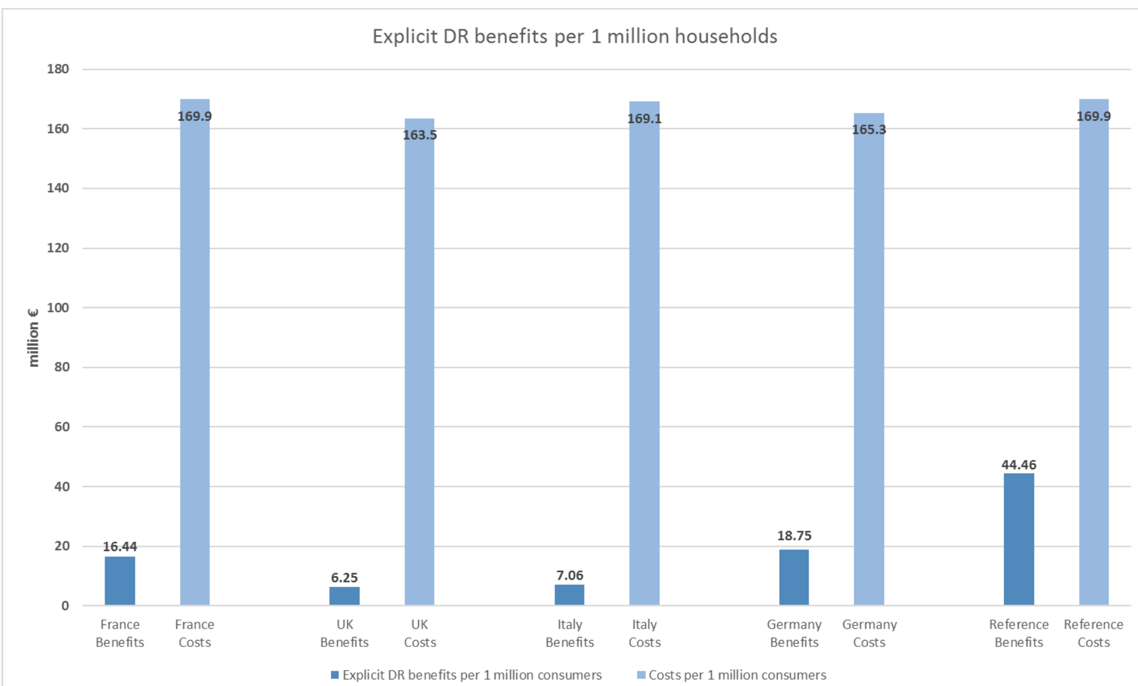


Figure 3: The costs and annual benefits of EDR enabled through smart appliances

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE

Years:	10.3	26.2	23.9	8.8	3.8

As can be seen, the payback time is still better than that of a power plant but too long to create a business case for residential consumers.

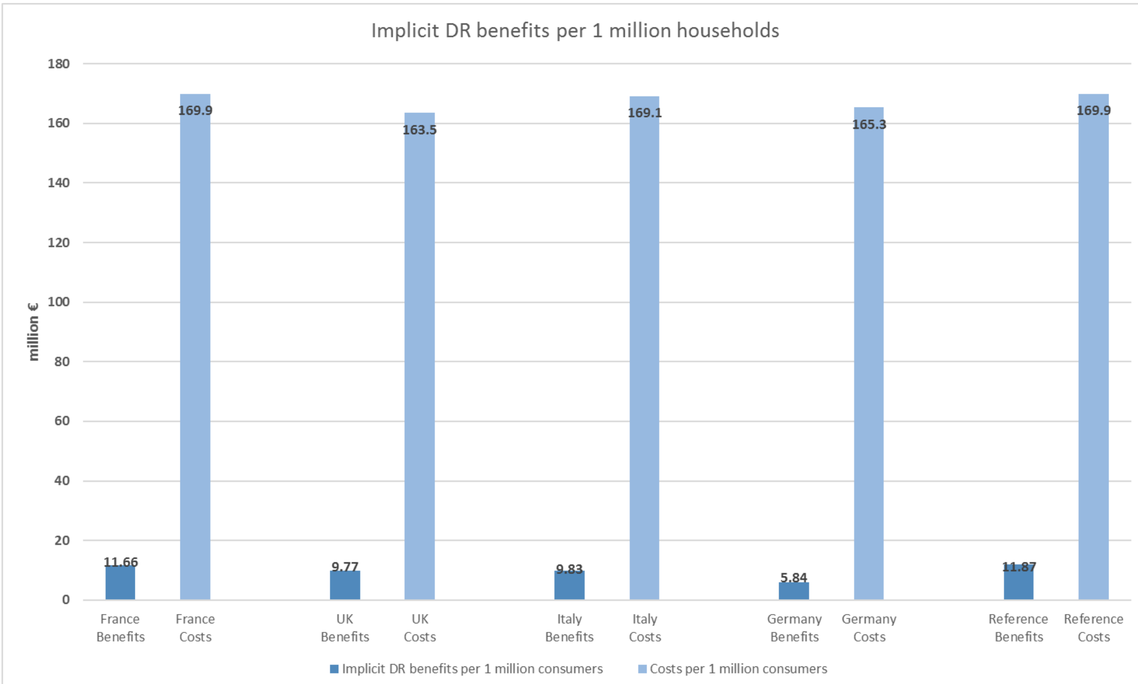


Figure 4: The costs and annual benefits of IDR enabled through smart appliances

Payback times	FRANCE	UK	GERMANY	ITALY	REFERENCE
Years:	14.6	16.7	17.2	28.3	14.3

Figure 4 depicts the pay-back time of IDR programs alone. These calculations indicate that equipping European homes with smart appliances for dynamic pricing programs alone, is not cost effective at today's prices. This is true even for the 'ideal' reference country scenario. Technology costs are too high and electricity costs too low. For the industry, this is non-news: consumers do not buy smart appliances to participate in a dynamic pricing programme alone, nor would this be optional.

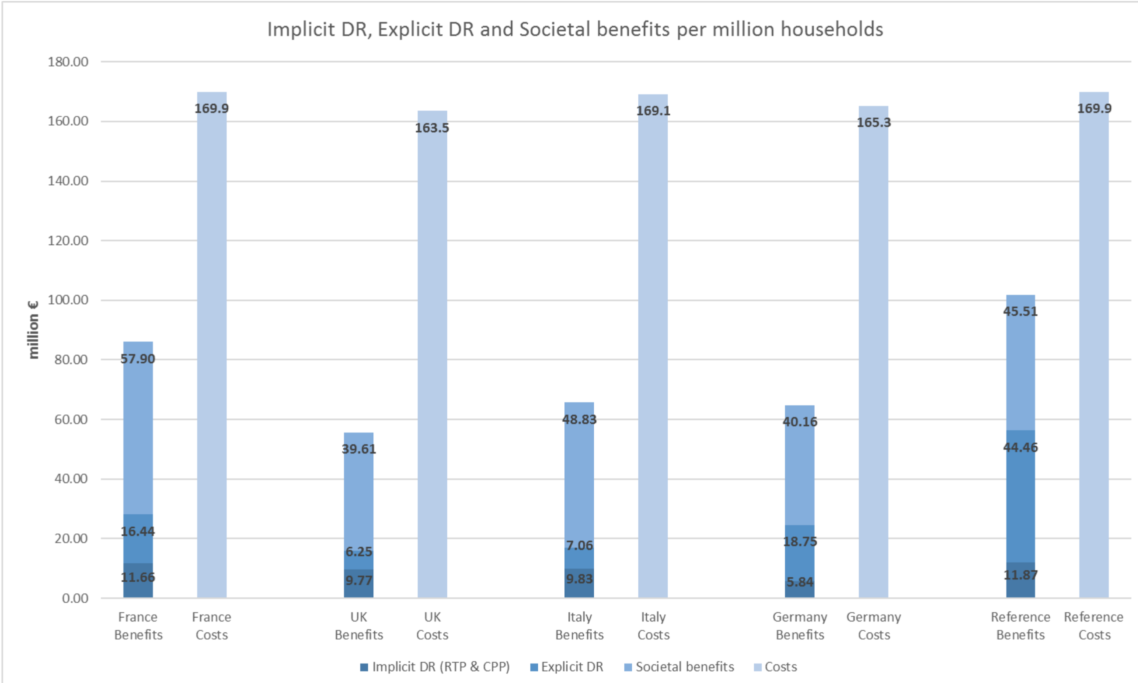


Figure 5: Annual IDR, EDR and societal benefits and related costs per million households

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	2.0	2.9	2.6	2.6	1.7

Figure 5 adds the societal benefits of Demand Side Flexibility to the direct earnings of consumers and puts these against the costs of the smart appliance package.

These societal benefits, created by lowered whole market trading costs, have been quantified by RTE and RAP [15] independently. They are also part of FERCs (Federal Energy Regulatory Commission) calculations for the benefits of DR in the USA. When prices no longer go above a certain price threshold – traders no longer have to hedge above this price. The entire cost of the market is therefore reduced. This has a significant impact on the cost of a particular hour of electricity, for example, if the average MWh price is reduced €1 – and 1,000 MW are traded that hour – the whole market saving is €1,000 for that hour. This creates a robust societal benefit from demand side flexibility in lowered costs for electricity. These benefit all consumers, both those on and off the

[15] Baker Phil, 'Benefiting Customers While Compensating Suppliers: Getting Supplier Compensation Right' Regulatory Assistance Project, 2016 AND, RTE "Expérimentation sur la valorisation des effacements de consommation sur les marchés de l'énergie (dispositif "NEBEF 1")." Retrieved from http://www.rte- france.com/uploads/media/pdf_zip/alaune/2013_10_16_ NEBEF_Rapport_de_consultation_Vdiff.pdf

programs. As can be noted, the benefits to society are higher than the benefits to the consumers on the programs. This argues for public support of the technologies.

The ratio of benefit per MW of DSF to societal benefits through the reductions in the whole market clearing costs, is getting smaller with every MW added – the impact of DSF per MW is therefore reduced, as the peaks are already clipped and there is less impact on the price. This tendency is taken into account in these calculations.

Findings in detail

France: IDR and EDR – both providing Demand Side Flexibility have the highest societal value in France per million households. This is due to the high peaks in the energy prices, driven by electric heating on cold days. Lowering these peaks provides significant societal benefits.

Germany: The societal benefits are smaller compared to France. The wholesale market costs are suppressed today due to the large influx of subsidized renewables[16], on top of this German households use less electric heating and therefore weather related events do not create the same consumption driven price peaks. As regulations and consumption patterns change, the value of demand side flexibility could again increase particularly within the 15-minute market designed to help balance intermittent renewables. (Progress will of course depend also on the level of subsidies introduced for other forms of generation, such as coal, and the demand side's access to these subsidies and also on the introduction of Smart Meters). Again, the importance of competitive, open markets is clear.

Italy: When societal benefits are included in the pay-back time, only 2.6 years are required to pay for smart home equipment for 30% of Italian households. This demonstrates again that as with many other forms of energy saving and environmentally beneficial programs, the benefits go primarily to the society as a whole, rather than only to the individual household concerned. The payback time for Italy is the same as Germany.

UK: The UK has the longest pay-back time for smart appliances, 2.9 years, again due to the low average consumption and low balancing and wholesale prices. Low prices can be

[16] Note that French nuclear is also state supported, however the mechanism and generation type is different and therefore the impacts are spread accross the market.

a sign of a well functioning market, and should not be understood as negative on their own.

Developments: Prices are already low in the UK but the government has now also introduced a Capacity Market, which suppresses whole market prices as generators have access to a long-term subsidy and do not need to earn all revenue from the market. Unfortunately, again, this subsidy/support has been freely accessible for generators only. Though regulators claimed the Capacity Market would be open to all forms of capacity (including demand and renewables), in reality the design strongly favoured existing coal and gas resources as well as some forms of new build generation assets, such as diesel generators. However, as this fact became obvious to all, the rules are gradually being adjusted to allow consumer load to compete. This will eventually allow load from smart appliances to also access capacity payments but will continue to suppress market price signals across the UK.

Capturing the full benefit of DSF requires that the technologies are ubiquitous and that they are competing within an open and fair market structure. They cannot adequately compete against resources which have access to state support or direct subsidies unless these subsidies are technology neutral and also accessible to smart appliances. However, ideally – subsidies for all resources, would be reduced and resources could compete in an open market.

The charts indicate that smart appliances participating in Implicit and Explicit Demand Response only have a pay-back time of between 8 and 20 years without the societal benefits. This will be too long from a single household perspective. They will not participate in DSF on the merits of this single business case alone. However, we should keep in mind that this is still **shorter** than the average payback time of a generation assets, which indeed take longer than 30 years today in Europe or are simply no longer feasible to build at all. Taken together with the societal benefits, the payback time is reduced to 2 to 2.9 years. From society's perspective, it would be cheaper to pay for smart appliances and to enable the programs, than to pay for generation units as is done now, (without even considering lowered network costs).

In conclusion, **the keys to significant savings** on the part of consumers are price peaks allowing them to gain better value from their flexibility, large flexible loads in homes such as heating or cooling and ubiquitous access to the required technologies. This argues against Capacity Markets and other forms of generation supports and subsidies present for coal, gas and nuclear today as well as renewables, which dampen market signals. It argues for the rollout of smart meters and **ubiquitous** rollout of smart technologies (built in and ready to use, off the shelf etc.) as only a robust level of consumer participation in programs allows for societal benefits to emerge[17].

3.2 Automated Energy Efficiency

The energy efficiency of a home can be improved through multiple means: new windows, insulation, lighting etc. can be installed to lower consumption. These will bring significant benefits and may also increase comfort. The payback time on investment will depend heavily on the cost of the measure, the cost of the financing and the price of electricity.

However, these investments in improved infrastructure and efficient equipment will not be discussed here. Rather smart appliances allow for improved control and the optimal use of what already **exists** in the home. As such, they have some of the best payback times of any efficiency technology available today. While even improved lighting will (usually) require a payback time of between 2-3 years for commercial sites, and new windows 20+ years, the longest average payback time for adding intelligence to appliances is between 2-3 years. This is borne out by current commercial experiences, where the sale of smart appliance capabilities for small businesses are paid back within 3-6 months.

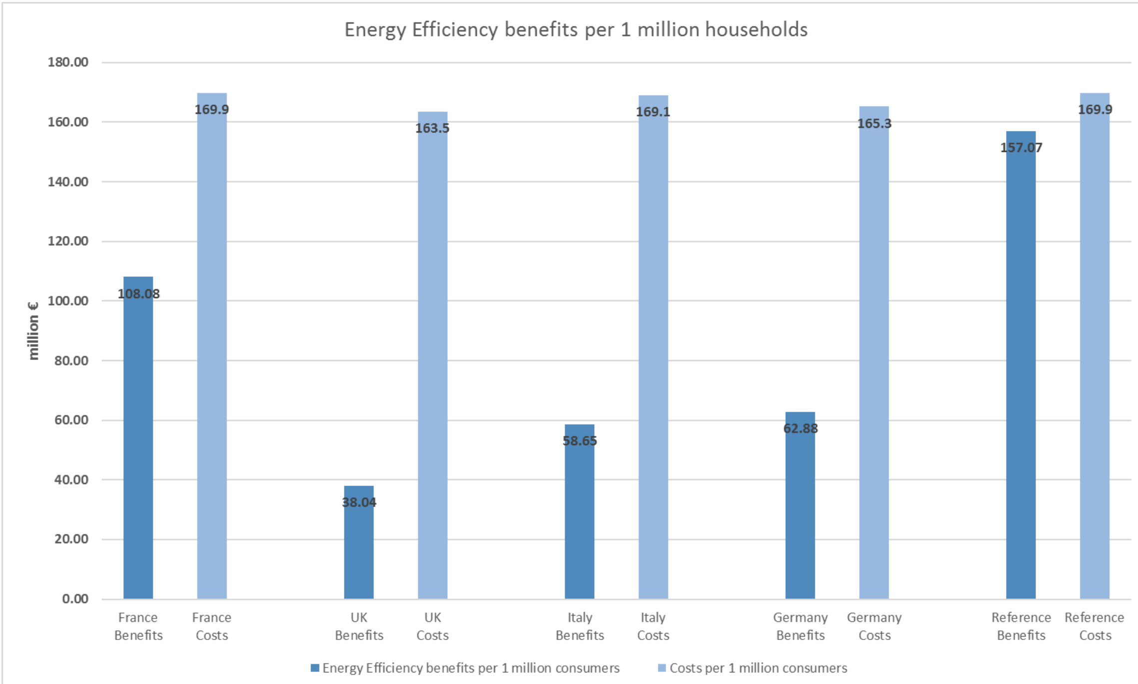


Figure 6: Costs and annual benefits enabled through automated energy efficiency using smart appliances

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	1.6	4.3	2.9	2.6	1.1

Findings in detail

France: has the highest average electricity consumption of the group. Therefore, French consumers' pay-back time for smart appliances would be only 1.6 years through energy efficiency alone – even given their relatively low retail electricity costs.

Germany: Though wholesale market costs are low in Germany, consumers pay relatively high retail electricity prices due to taxes and fees for the support of intermittent generation. Therefore, even though average national consumption is lower than in France, German consumers stand to save the same amount from automated energy efficiency services, with a payback time of only 2.6 years for the technology.

Italy: Italian houses are not efficient – indeed it is difficult to find an apartment or home rated better than F or G for efficiency. However, Italian homes use little heating or cooling and are also dependent on gas for their cooking. This low average consumption explains the lower potential savings from automated energy efficiency. Nevertheless, the payback time of smart appliances would be only 2.9 years.

UK: the UK has both low average electricity consumption and low retail market prices compared to the other countries include. Therefore, again the benefits of home automation are lower if only electricity is included. However, in the case of the UK; this gives a false picture. Much of the heating in the UK is performed using gas. Therefore – if smart thermostats were ubiquitous for gas as well as electricity – financial savings would be significantly improved. Indeed, for parts of the UK, the investment returns would closely resemble those of France.

Reference Country: the payback of 1.1 years is enabled through high consumption (France) and relatively high retail prices (Germany).

Conclusion: Payback times for smart appliances through the optimized use of existing appliances (energy efficiency) is far shorter than for most technologies which are already regulated according to national efficiency standards, for example lighting, windows, wall insulation etc.

The efficiency capabilities of smart appliances create an adequate business case on a national level, even without added DSF[18] but will be unlikely to attract investment from consumers on their own, due to the small monetary sums involved.

In order to bring these benefits, the technologies should become interoperable and ubiquitous. They should arrive smart but able to communicate between brands, as customers cannot be expected to purchase all appliances from a single manufacturer.

Today, payback times are decided by the existence of large loads in the home, such as electric or gas heating or cooling, the retail cost of electricity, and the portion of this cost which are dependent on consumption levels (therefore not fixed fees). This creates a relatively direct relationship between using less and lowering electricity costs.

However, in future this may change, the network fees (approximately 20-30% of the electricity bill) are gradually being increased and separated fully from consumption levels. Government are also considering putting punitive VAT taxes on prosumer generated electricity (e.g. in the Netherlands and in Spain). In other words, governments and infrastructure companies (such as DSOs) see the increasing **independence** of consumers from the electricity system as a loss in revenue. Governments will lose

[18] For prosumers who own solar PV panels the payback of smart appliances is only a matter of months, as the self-consumption is maximized (assuming self-consumption is legal).

significant tax revenue they now earn through the DSOs, TSOs, and directly on electricity sales, and infrastructure companies (DSO and TSOs) are concerned over the fact that they are being required to maintain similar infrastructure but with less usage. All of them are looking for ways to guard their revenue streams [19] (ideally without having to significantly improve their own efficiency in order to do so). Therefore, the current 'easy' direct relationship between electricity savings and lower electricity bills **should not** be taken for granted.

3.3 Aggregated Costs and Benefits

Figures 7 and 8 depict the costs and benefits of smart appliances using their full control capabilities for Implicit Demand Response, Explicit Demand Response and energy efficiency.

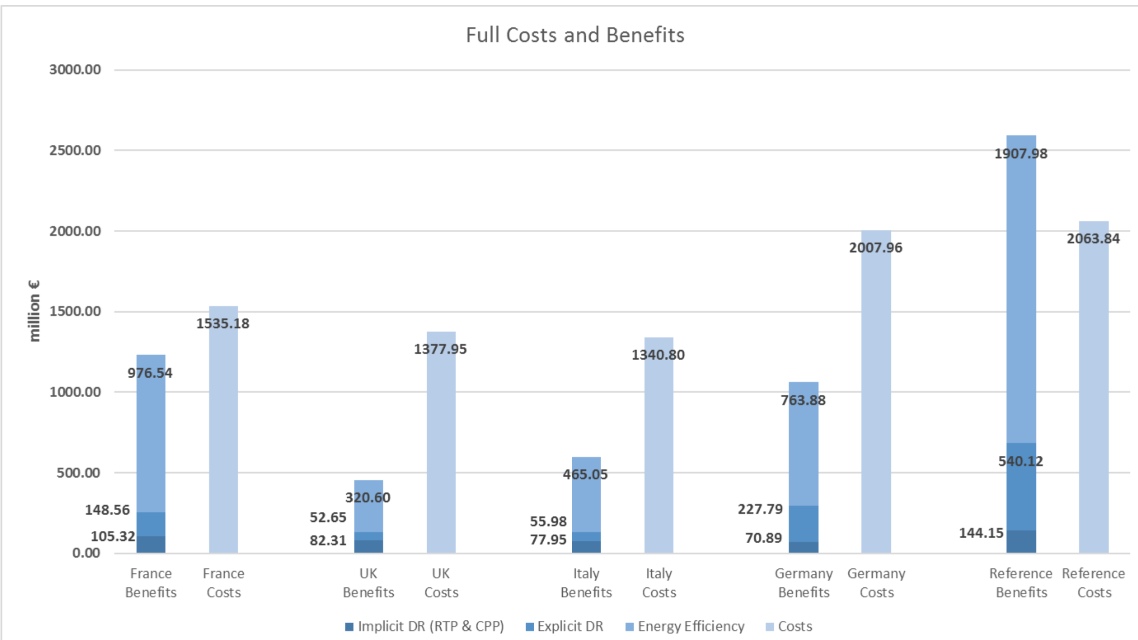


Figure 7: Annual full consumer benefits and one-off costs per country

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	1.2	3.0	2.2	1.9	0.8

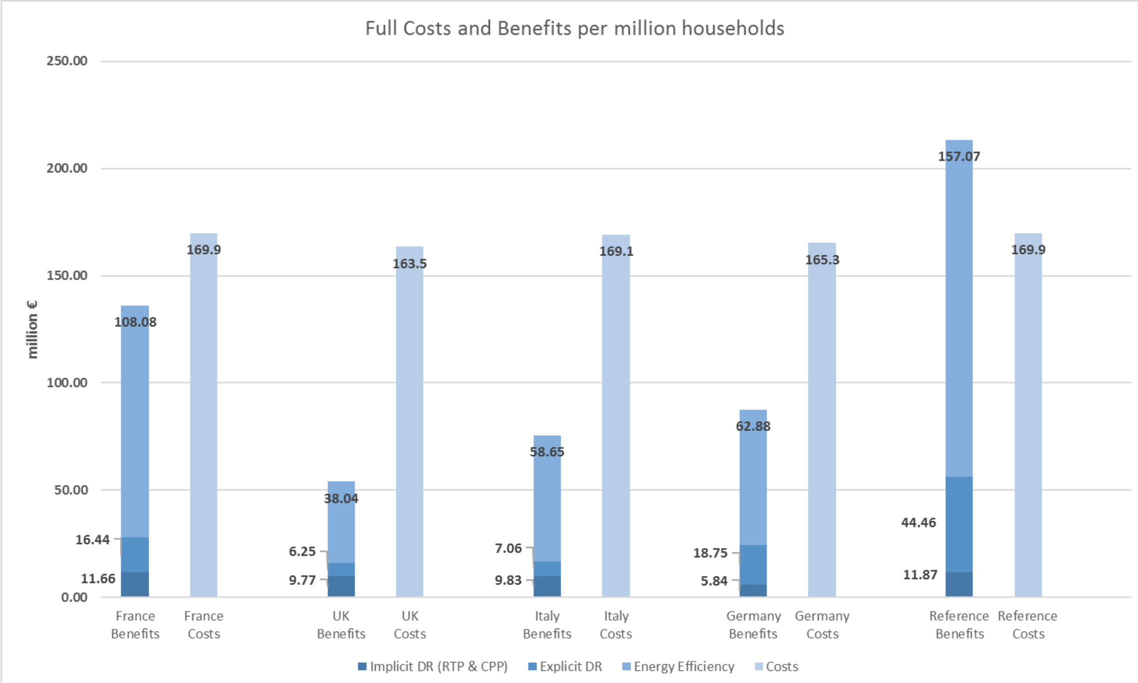


Figure 8: Annual full consumer benefits and one-off costs per million households

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	1.2	3.0*	2.2	1.9	0.8

Pay-back times here, range between 1.2 and 3 years depending on the country. In the optimal scenario for the reference country, payback times average only 0.8 years.

Findings in detail

France: the peak prices and high average electricity consumption gives a good opportunity to benefit from improved energy efficiency and flexibility programs enable by smart appliances in France. The payback time here is only 1.2 years.

Italy: The payback time for the average houshold in Italy would be 2.2 years. That said, this would create approximately €54 per year in savings for the average home, probably insufficient to make a single purchasing decision. The options would need to be sold as part of a larger package, such as for example security services, health, style, control etc. as discussed in the introduction and user stories. Due to the relatively low purchasing power of many households and a high awareness of energy consumption, direct monetary savings are going to be understood differently in Italy than they might for example in France or Germany.

Germany: The impact of low average national consumption is offset by relatively high retail and balancing prices. Therefore the payback time for a home equipped with smart appliances would be an average 1.9 years.

UK*: a UK consumer without gas or electric heating would have a 3 year payback time for smart appliances. This is due to a combination of low average consumption, low retail prices relative to the other markes and low balancing costs. However, many homes in the UK indeed use gas heating and therefore for these homes' pay-back time will be closer to 1 year rather than 3.

Reference Country: depicts the potential of smart appliances as electricity consumption grows per household. Of course these returns are only possible if competitive markets are allowed to develop and generation assets are not subsidised to ensure they do not go out of business. However, as of today all evidence points toward more rather than fewer forms of subsidies of fossil fuels. In this case, demand side resources must have access to the same levels of subsidy as generation assets, for example access to capacity markets, reserves markets and direct subsidy if these are provided to other resources.

In reality benefits accumulate over time while the purchasing decision is taken once. For example, if 30% of UK households made full use of smart appliances, the savings would range between €456 million per year not counting savings from gas heating. This is €4.56 billion over 10 years. If the same percentage of French households had smart appliances the total savings for these consumers would be €1.231 billion annually. Over 10 years the savings would be €12.31 billion. Similarly, in annual savings would be Italy 599 million and 5.99 billion in 10 years, in Germany annual savings would be €1.063 billion annually and €10.63 billion over 10 years.

Though it is possible to argue that running the programs will come at a cost and upgrades in technology would be required within 10 years – and therefore the programs would not remain free after first payment – it is equally possible to argue that as technology improves and electricity costs continue to rise (which they are expected to do) the value of smart appliances is under-valued rather than over-valued here. Added to this, these calculations include no quantification of avoided costs in network upgrades, societal benefits nor indeed the cross-border impact of one country's efficiency lowering balancing costs in the neighbouring country. Therefore, it is fair to at least multiply known benefits over time. Counted across Europe, improving the intelligence of the European home is as good or better an investment than many other similar programs.

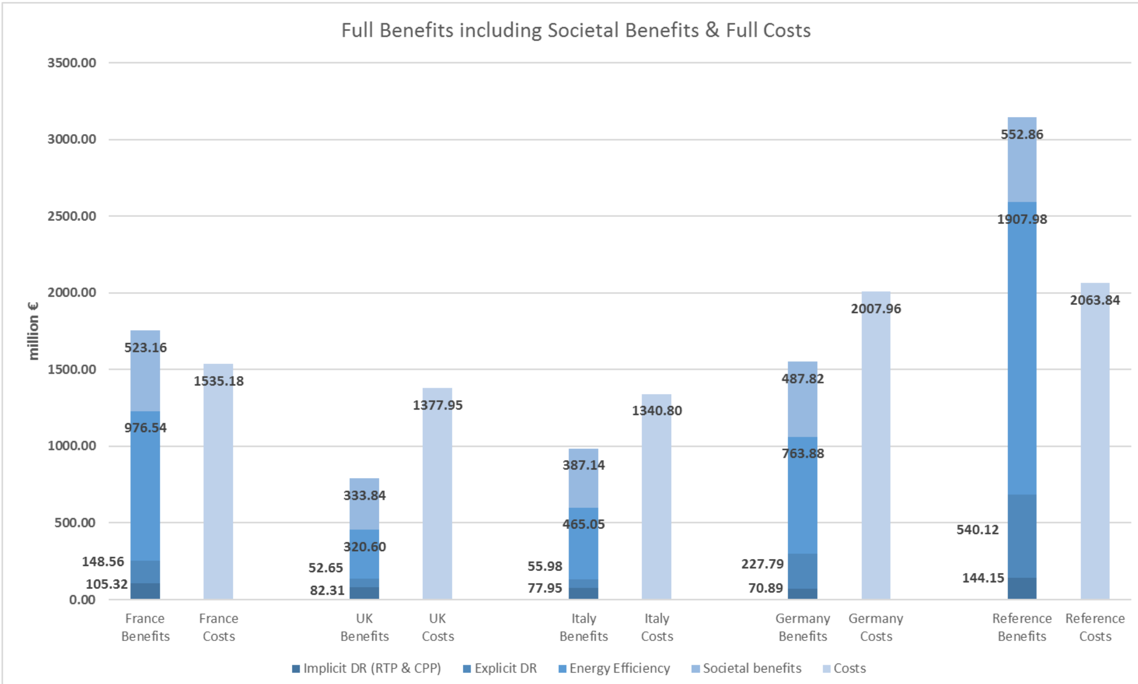


Figure 9: Annual full benefits including societal benefits and related one-off costs per country

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	0.8	1.2	1.0	0.9	0.6

Figure 9 adds the societal benefits on top of the benefits earned by households in the programs. In reality, when these are taken into account, the payback times are reduced to a year or less for all countries (including the UK). Again, these numbers are conservative and do not quantify all surrounding impacts, such as lowered gas consumption, cross boarder benefits, potential reduction in network fees etc.

Split incentives: Though payback times are good (or excellent), complexity is introduced when one considers that the benefits and costs are spread across multiple players. This complicates the task of creating an attractive business model for individual households. While participating households would most likely pay for the smart appliance technologies, benefits would be spread between themselves, TSOs, DSOs, their retailer/aggregator, the rest of the national population and even neighbouring countries. Therefore, while the active household takes most of the costs, they will not gain access to the full benefits. Again, a short payback time does not always lead directly to a compelling sales proposition. Bundled offerings, provided through a communications company, an insurance firm, a security firm, a health services provider etc. help to over come this issue. The business model is then combined with a wider range of services, which can create a clearer case for an individual's purchasing decision. That said, seen from a holistic perspective the business case for equipping homes with smart appliances is positive and should motivate governments looking to improve energy efficiency and support the integration of renewables.

3.4 Results per household type

All consumers are individuals acting within their own set of circumstances. One important factor in the payback time of smart appliances is the amount of load consumed within a particular home. Figure 10 depicts payback times for houses of different sizes, small, medium and large according to the national average. It is important to note that the average consumption of a high consuming home in France consumes almost 3 times as must as a high consuming house in Italy.

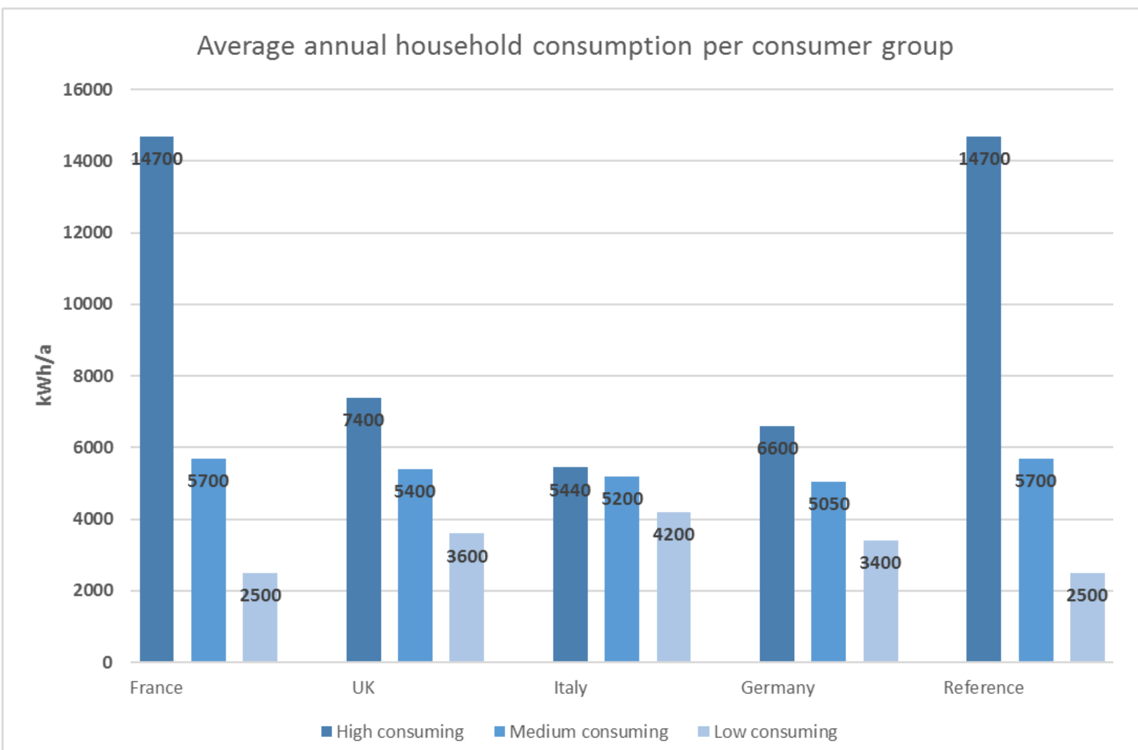
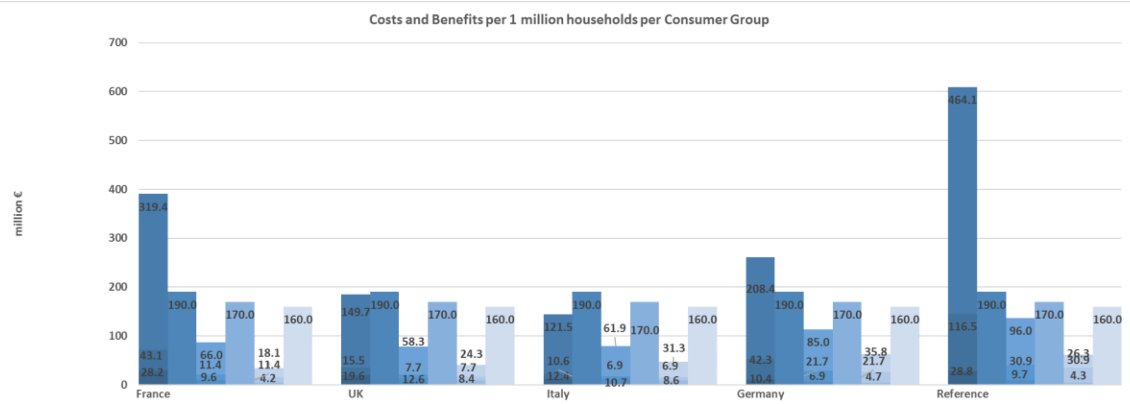


Figure 10: Average annual household consumption per consumer group

When households are broken down in this manner the direct correlation between, the payback time of smart appliances and the consumption level of the household becomes clear. Figure 11 provides and overview of these results.

France: High consumers in France have a payback time of only 6 months, a strong business case, while small consumers will need to use their technologies for 4.7 years. This discrepancy is due to the high use of electric heating in large French homes, which drive up consumption to 14,700 KWhs per year.

Germany: The spread between the highest and lowest payback times in Germany are lower than in France, as there is less difference between household consumption levels. High consuming Germans would pay-back smart appliance technologies in 0.7 years while low consumers would have to wait 2.6 years.



	France	UK	Italy	Germany	Reference
Costs LC	160.0	160.0	160.0	160.0	160.0
Energy Efficiency LC	18.1	24.3	31.3	35.8	26.3
Explicit LC	11.4	7.7	6.9	21.7	30.9
Implicit LC	4.2	8.4	8.6	4.7	4.3
Costs MC	170.0	170.0	170.0	170.0	170.0
Energy Efficiency MC	66.0	58.3	61.9	85.0	96.0
Explicit MC	11.4	7.7	6.9	21.7	30.9
Implicit MC	9.6	12.6	10.7	6.9	9.7
Costs HC	190.0	190.0	190.0	190.0	190.0
Energy Efficiency HC	319.4	149.7	121.5	208.4	464.1
Explicit HC	43.1	15.5	10.6	42.3	116.5
Implicit HC	28.2	19.6	12.4	10.4	28.8

Figure 11: Costs and annual benefits per million households per consumer group

Payback times	FRANCE	UK	ITALY	GERMANY	REFERENCE
Years:	0.5/2.0/4.7	1.0/2.2/4.0	1.3/2.1/3.4	0.7/1.5/2.6	0.3/1.2/2.6

Italian: High consuming homes would have pay-back times of 1.3 years while low would need to use their appliances for 3.4 years.

UK: High consuming homes in the UK would only require 1 year to pay back their appliances while low consuming households would require 4 years. Again, this indicates that homes which use electric or gas heating would have a strong business case for smart appliances also in the UK – even if the national returns on investment are not particularly strong.

This spread in payback times across types of households brings out an important factor in releasing any consumer oriented programme. People are individuals and their drivers, needs and capabilities are different. These will shape how they react to an offering. In the electricity industry, this reality is often experienced as a barrier to programme rollout. However, this perception is due to the fact that electricity companies are used to selling electricity – not a differentiated product but rather something that today is seen almost as a right. However, energy management services, are much more like any other product or service – clothing, cars, interior design – some people will want and need one thing and some other another and some don't want any of it. This does not make the products being sold a failure, it means they are in a competitive market with other viable options. It is therefore good news that large consumers in these countries have payback times of 6 months to 1.3 years and medium consumers 1.5 to 2.2 years. It means that in all the markets included in this study, purchasing smart appliances could be a financially viable decision for a significant portion of the population. The fact that adding intelligence to a home is not going to be realistic for everyone should be obvious without a cost-benefit analysis.

3.5 Energy and Capacity Savings

The focus of this study is to perform a cost-benefit analysis according to real market prices and actual results from pilots and regional rollouts, which have used smart appliances. However, smart appliances are not an end in themselves, nor are they usually purchased for their financial potential alone, rather they are a means of optimizing and lowering consumption and improving the integration of clean resources such as wind and solar. Therefore, both the potential of smart appliances to save energy (MWhs) and to create flexible capacity, which can be used to balance renewable generation (MW) have been calculated.

Capacity Building (MW)

When solar and wind farms need to be balanced by fossil fuel generators, two significant issues occur. **First**, the cost of the capacity is at least doubled. As wind turbines and solar panels generate electricity when the sun shines or the wind blows, a complete second set of generators is required for when wind and sunshine are not available. This is expensive. **Second** the continuous use of fossil fuels to balance wind and solar can remove all carbon savings. This is particularly true when intermittent renewables are balanced using the cheapest available resource – coal. The impact can be seen directly – for example Germany's carbon output has increased, substantially the more they have installed wind and solar. This is due to the unfortunate fact that the subsidised renewable generation drives down market prices, which in turn means that only low cost coal generators are able to compete, and cleaner resources such as gas are outbid. This practice of paying twice the money for a highly polluting energy system - is unsustainable (counter-productive and irresponsible). As Europe (including Germany) is serious about lowering CO^2 output at a reasonable cost – demand side resources become ever more important and must be taken seriously.

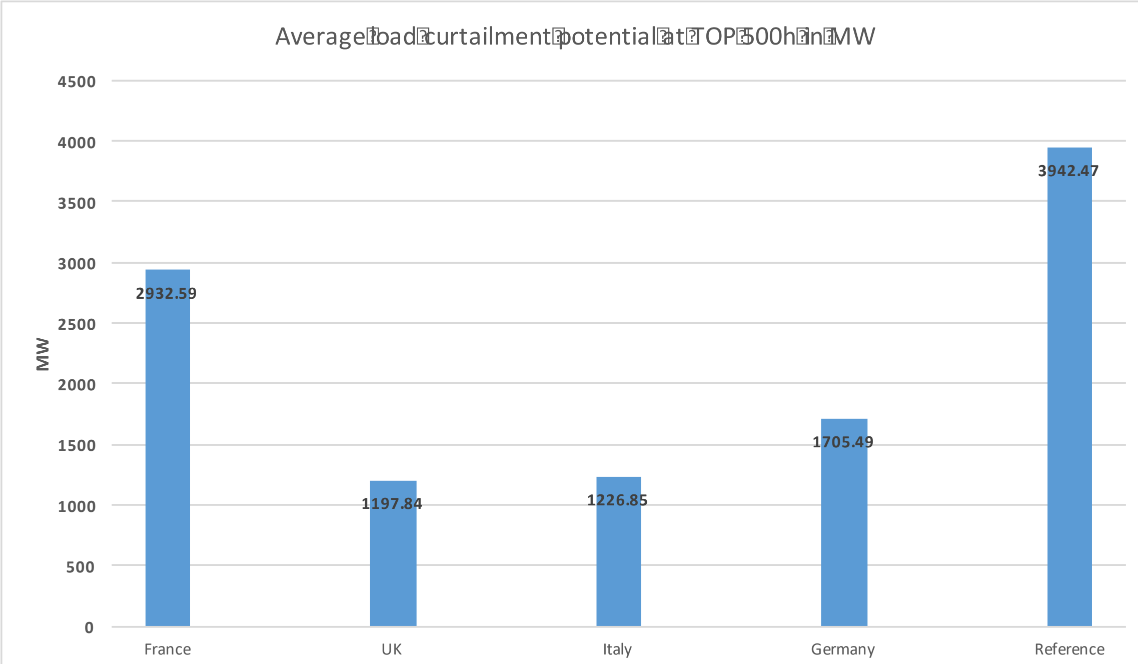


Figure 12: Average load curtailment potential at TOP 500 hours in MW

DSF is a competitive source of flexibility in Europe already today at current prices. As has been noted, a gas fired generator can no longer compete in the German electricity market, even if payback times of over 30 years are accepted, while the payback time for smart appliances is an average of 1.9 years. From a societal perspective, it therefore makes financial sense to empower consumers to support the integration of renewables rather than to balance renewables using highly polluting lignite coal, as is current praxis. The same is the case for the other markets. Below, the potential capacity created by smart appliances is compared to an average 500-MW power plant.

France: 2,933 MW of total flexibility would be created with a payback time of an average of 1.2 years in France. This is the equivalent of almost 6 500-MW coal or gas fired plants or 3 nuclear power plants.

Italy: 1,227 MW of total flexible capacity could be created in Italy, with a payback time of 2.2 years for the technologies required. This is equivalent to 2.5 500-MW coal or gas fired plants. The significant difference being that the income earned would go to Italian households and would not be used to purchase polluting fuels.

Germany: 1,705 MW of total flexible capacity could be created in Germany with an average payback time of 1.9 years for the technologies required even at today's prices where the building of new capacity is considered impossible in Germany due to the low electricity market costs. This is equivalent to 3.5 500-MW power plants and makes smart appliances significantly more competitive than any other generation source available.

UK: 1,198 MW of total flexible capacity could be created in the UK with an average payback time of 3 years. This is the equivalent of 2.3 500-MW coal or gas fired power plants. Again, plants are considered impossible to build today in the UK due to the low market price and subsidies in the form of a capacity market has been introduced.

Energy savings (MWh)

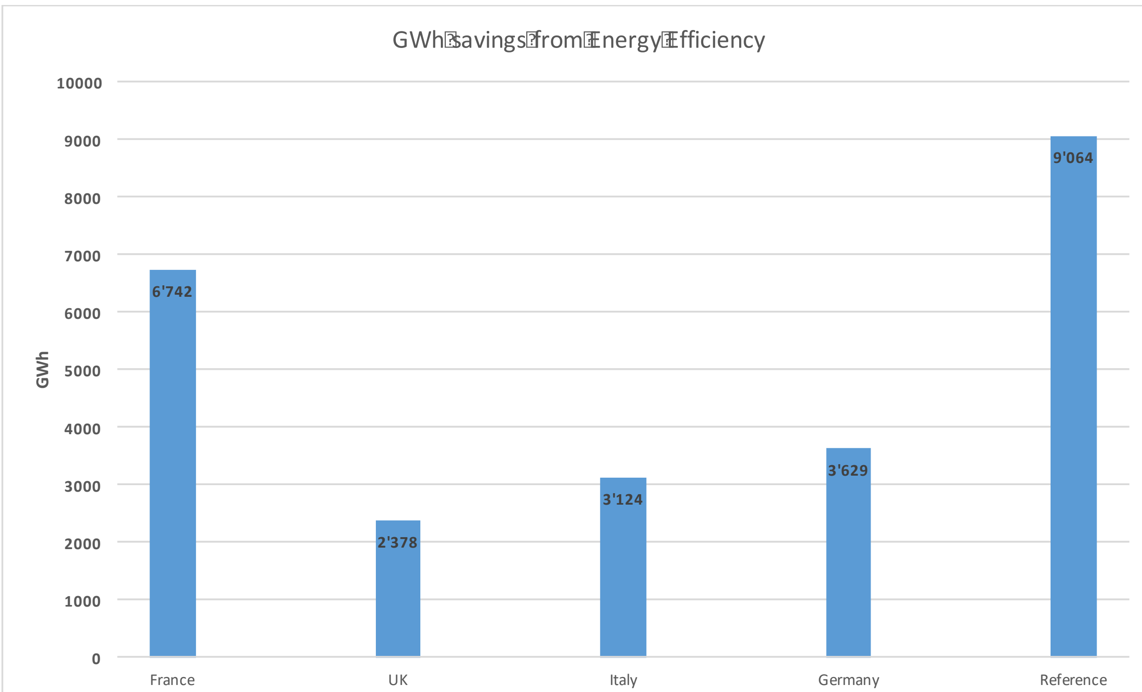


Figure 13: Annual GWh savings from energy efficiency per country

Figure 13 depicts the amount of potential energy savings in GWh generated through smart appliances. In the country analysis, we then answer the question of how many homes (according to the national average consumption) could be powered using this energy.

France: An average household in France consumes 6,370 kWh annually. A saving of 6,742 MWh annually would therefore power 1,060,000 French homes, all year every year as long as the programs remained in place.

Germany: An average household in Germany consumes 4,200 kWh per year. The savings of 1,629 MWhs annually would therefore supply 863,000 Germany households for duration of the program.

Italy: An average household in Italy consumes 4,600 kWh annually. A saving of 3,124 MWh annually would therefore power 679,000 Italian homes for the duration of the program.

UK: An average household in the UK consumes 4,100 kWh annually. The saving of 2,178 MWh annually would therefore power 570,000 UK homes for the duration of the program.

3.6 Relational sensitivity analysis

Below are graphs describing the relationship of different key variables driving value. As can be noted, while certain variables such as electricity prices and payback times have a correlated and proportional relationship, with others the impact decreases in a proportional manner to growth, for example as uptake rates continue – benefits per new consumer decrease.

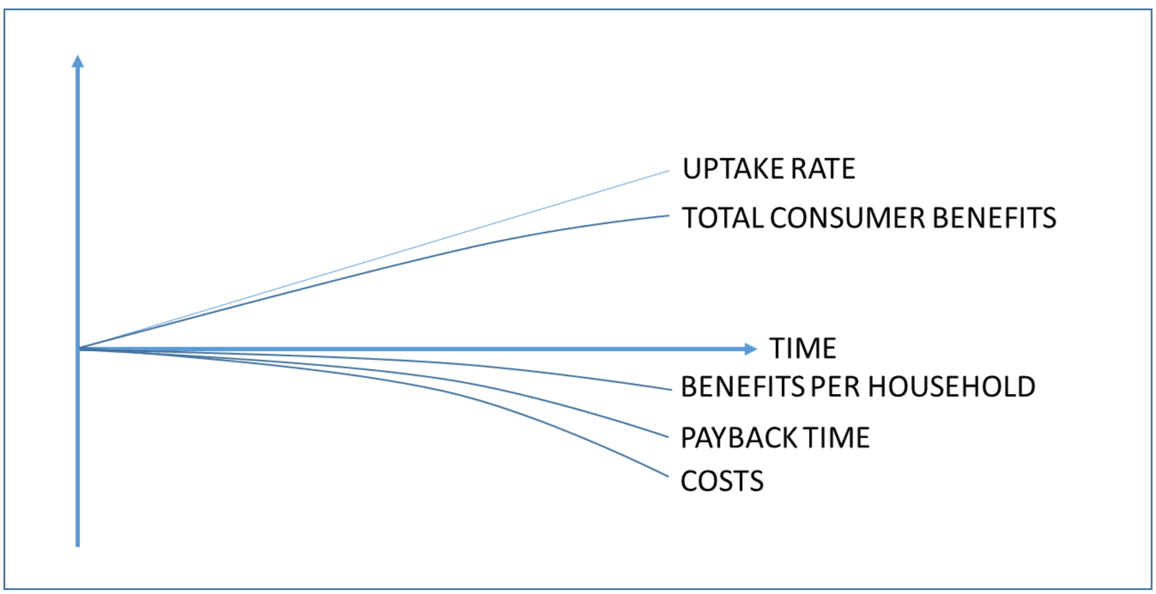


Figure 14: Relationship of uptake rates, total consumer benefits, benefits per household, payback time and costs

- With increased consumer uptake rates and the integration of smart appliances, financial benefits to the country increase in a proportion only until peak consumption and whole market costs are reduced. At this point the two gradually decouple.

- As consumer uptake increases benefits per household will gradually decrease because marginal benefits to the system will start to be reached.
- As costs will go down super-proportionally to the uptake rate, payback times will decrease, even if at a slower rate.

Therefore, the benefits of individual end consumers are sensitive to the uptake rates and benefits already provided to the system as a whole. The more other consumers have already achieved already, the less any individual consumer will earn in proportion, even though overall their payback times and costs will be reduced.

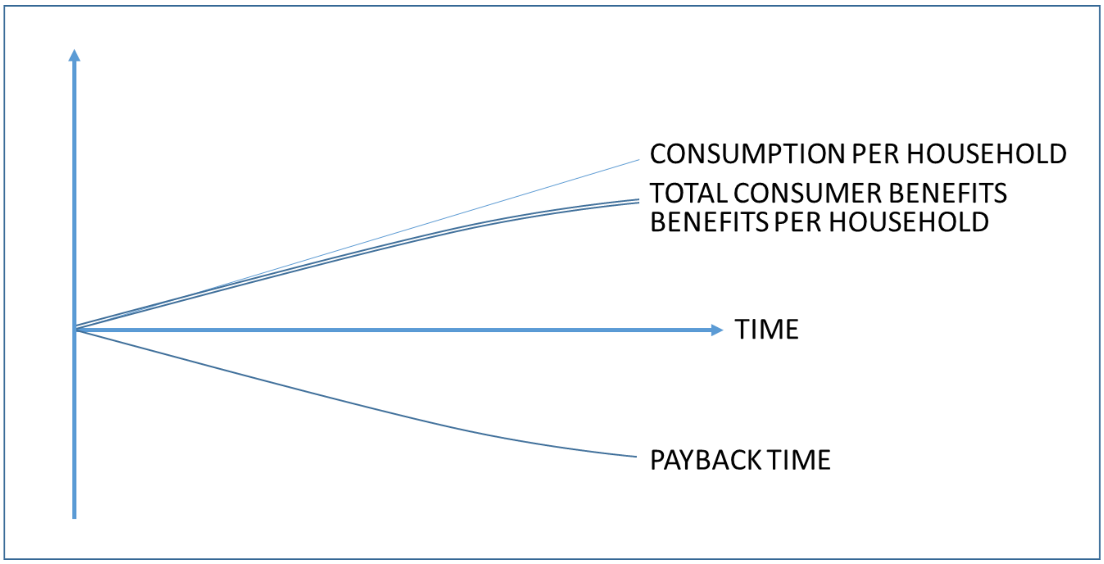


Figure 15: Relationship of household consumption, total consumer benefits, benefits per household, costs, and payback times

Figure 15: As consumption per household increases, overall and per-household benefits will develop side-by-side assuming there is no change in uptake rate. Payback time decreases in direct proportion to higher levels of consumer benefits, as costs are projected to remain the same.

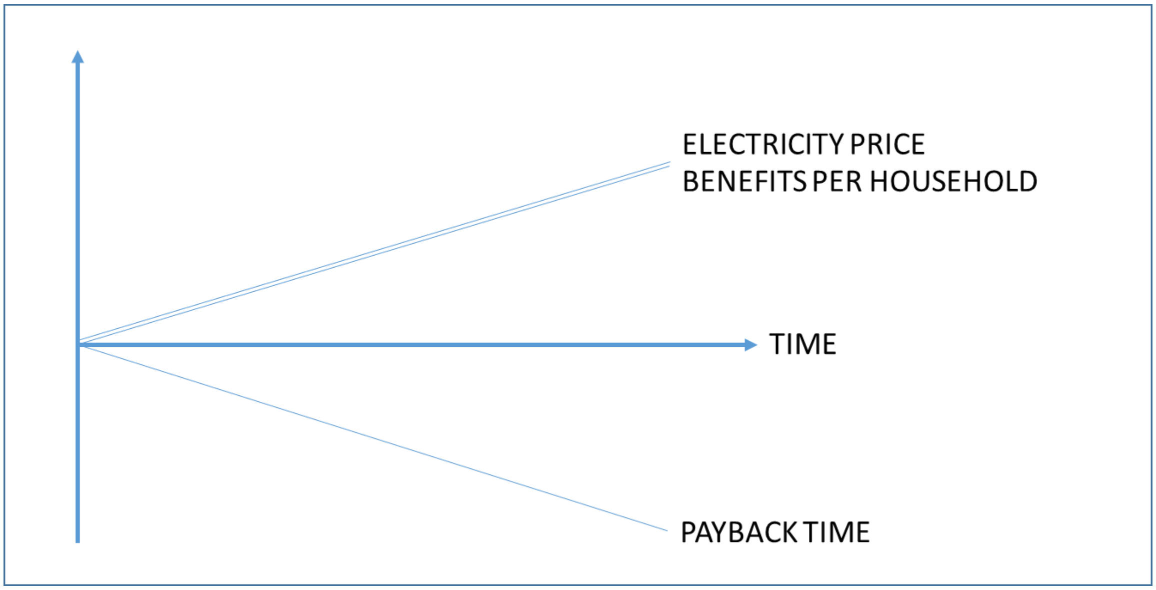


Figure 16: Relationship of electricity price benefits per household and payback time

Figure 16: With the electricity price going up, benefits for households will increase equally, and (assuming steady costs) payback times will decrease likewise.

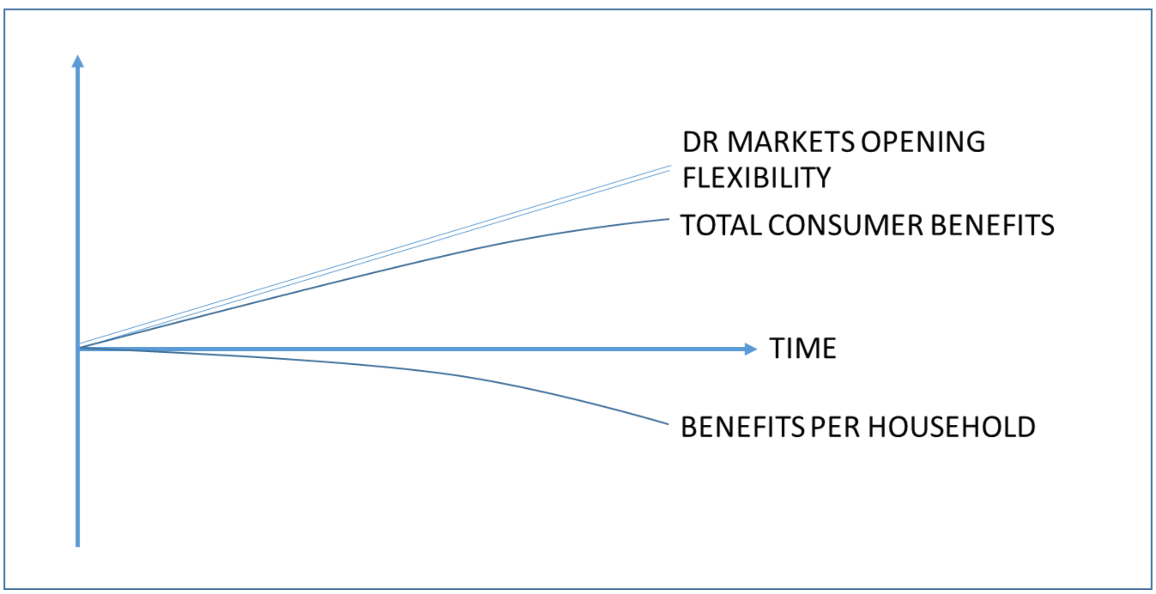


Figure 17: Relationship of DR market opening, societal benefits and benefits per household

Figure 17: As balancing markets start to open to DSF, the amount of flexibility will increase steadily, with societal benefits growing in proportion. However, as markets become more liquid through improved competition, these benefits decouple, with benefits per household decreasing.

Section 4: Market Participants Benefits from smart appliances

DSF can help to avoid inefficiency in the market and allay the concerns of some governments and regulators that the future mix of electricity generation capacity delivered by the market may not meet demand at optimal costs. Such concerns are likely to grow as the share of renewable energy generation increases, creating additional interest in the flexibility ensuring sufficient firm capacity as well as in tools needed to manage fluctuation in generation and demand. Therefore, while it should be noted that flexibility will not replace traditional investment, increased integration of distributed energy resources and the growing peak demand for electricity, will drive the need for increased flexibility and customer engagement in order to maintain an affordable energy system.

4.1 Purposes of DSF from utility perspective

Retailers, DSOs, TSOs and aggregators are businesses and they will offer flexibility services only when these services will provide a business benefit to themselves. This section therefore focuses on some of these benefits [20] and describes the users of flexibility services and the system users that can provide these services. It will also identify what services are required by the current market players and what services can be offered by flexibility providers.

Retailers (and/or BRPs)

Retailers acting in their capacity as Balance Responsible Parties (BRPs), are key users of flexibility. Currently the majority of flexibility in the electrical system is provided by conventional power plants. Energy trades are usually the result of long term bilateral contracts, while flexibility is typically required for the short-term planning of supply and demand. This planning is called portfolio optimization.

The wholesale markets are by far the largest and (theoretically) most liquid markets in any given Member State. Here, retailers look to buy sufficient energy either from their own generators or from the market, to supply their customers. In order to maintain

[20] The technical definitions of stakeholders (Retailer, BRP, TSOs, DSOs) for this section is based on the Smart Grids Taskforce paper (EG3) 2014

balance, they should buy the same amount of energy for any given time period, as their customers will consume.

This is part of their balance responsibility and each retailer will therefore become a balance responsible party[21]. Wholesale markets include futures markets but also intra-day and spot markets, where energy is bought and sold 15-60 minutes prior to the time of consumption. After this point, there is 'gate closure'. The wholesale market activity is at an end and the TSO is responsible to maintain balance from the time of gate closure to the moment of consumption. This is done through balancing markets and ancillary services.

Retailers may be required to pay the TSO for these services according to the amount that they were off in their balancing calculations. However, the company's generators may also earn from providing balancing and ancillary services to the TSO. This mechanism is different in various Member States, but the principle remains the same.

A retailer may therefore wish to lower their trading risk and balancing costs through the use of demand side flexibility. There are multiple examples of this being done successfully in Europe with high consuming residential households, such as EDF's tempo tariff. Many other retailers now offer IDR programs successfully: Dong Energy, Helsinki Energy, Scottish Power, Vattenfall… to name only a few. The installation of smart meters and appropriate regulations around electricity settlement are key enablers of these programs.

Transmission system operator

TSOs have been highly instrumental in Europe, enabling EDR and adjusting many of their regulations to allow large consumers to participate in the balancing markets. This is due to a clear business case for the TSO, as increased competition in the balancing markets both supports system security and lowers balancing costs. TSO flexibility requirements include demand adjustments both upwards and downwards, and provision of reactive power, as well as peak shifting. Today, consumers participate in all TSO driven markets successfully in at least one or two Member States if not more. As the Network Codes are implemented this number is expected to rise sharply. The path for consumer entry into the balancing markets is therefore clear and it is a matter of time, experience and continued regulatory and industry pressure before residential consumers are also able to provide services. For this to be possible however, smart appliances must be ubiquitous

[21] An independent aggregator must also contract with a BRP in order to maintain their own balance.

as balancing markets do not provide high enough payments to justify the purchase of smart technologies on their own.

Distribution system operator

DSOs do not make use of demand side flexibility today, nor is there significant progress in this direction. In theory, DSOs could make valuable use of demand side flexibility but in conjunction with smart grid improvements overall. This has been done successfully in the UK due to a significant change in regulation forcing an adjustment in the DSO business model. However, few have voiced interest in this possibility outside the UK. In cooperation with smart grid improvements DSO flexibility requirements would include generation and demand adjustments, generation curtailment and provision of reactive power, peak shifting. Example uses include:

- Long term congestion management: Currently, DSOs provide grid capacity (guaranteed access) that may not be fully used[22] due to for example, consumer behaviour or local consumption of electricity produced by Distributed Energy Resources (DER). With the rise in DER, the system cannot be designed to cater for all contingencies without significant investment in basic network infrastructure. Different levels of grid access and real-time flexibility could reduce or postpone investment needs, in theory.
- (E&G) Short term security congestion management: Network reinforcement could be deferred until they become more cost-effective than the on-going cost of procuring flexibility services. For this to be possible, DSOs should create regional markets where these services could be purchased. This process is not possible anywhere in Europe today.

Aggregators for domestic consumers

Unlike retailers, DSOs and TSOs, which have a range of responsibilities and market functions, aggregators are service providers only, and they succeed or fail according to how well they engage with consumers and create viable demand side resources. Aggregators today contract predominantly with large industrial users as these earn the largest single payments and provide the best business model for the aggregator.

[22] Even when fully used, the duration of the use is very short, in the range of a few hours per year.

However, the flexibility of domestic customers may be pooled by the supplier or aggregator. Remuneration for the consumer will depend on the contract.

In conclusion, there are multiple means for the capabilities of smart appliances to be used and to reach market within the current electricity market alone. Retailers can improve their service portfolios, aggregators can build independent businesses and TSOs can immediately lower balancing costs, thus improving system security. These are all possible today and taking place on a small scale. However, greater scale is key for the full benefits of smart appliances to appear.

5. Conclusions

A cost benefit analysis is meant to answer the question, is a measure worth the money - will it pay? The results of this study say, yes. When using smart appliances for DSF, they have a significantly shorter payback time than all forms of generation, while a solar panel in Portugal today will require approximately 6.5 years to payback, a coal or gas fired plant will only pay for itself after 25 to 30 years in Germany (at best) and a nuclear generator will simply not pay. Yet the average time required to payback smart appliances is between 1.2 and 3 years depending on the Member State, without including the value of societal or industry benefits. If surrounding benefits are included, payback times are under a year for the majority of consumers. This is less time than it takes to payback and average energy efficient light bulb on a commercial site. However, payback times are not the same as a compelling sales proposition and therefore surrounding supports are key for the rollout of smart appliances. Therefore, smart appliance capabilities should be built in to all appliances and communication interoperability should be set. When this takes place, communications, health and security firms as well as retailers and aggregators will create viable bundled services with greater ease, ensuring significant uptake and usage. Furthermore, key conditions such as the roll-out of smart meters and open competitive markets need to be improved. The European Commission and National Governments should encourage this development.

ANNEX I: List of acronyms and key terms

Aggregator

An Aggregator is a legal entity that aggregates the load or generation of various demand and/or generation/production units. Aggregation can be a function that is provided by an independent service provider or a retailer.

Ancillary Service

All services necessary for the operation of transmission system and distribution networks (including LNG facilities, and/or storage facilities for gas, these services include load balancing, blending and injection of inert gases and do not include facilities reserved exclusively for transmission system operators carrying out their functions.

Balancing Market/Trading Platform

Balancing Market means the entirety of institutional, commercial and operational arrangements that establish market-based management of the function of Balancing within the framework of the European Network Codes.

Balancing Portfolio

Grouping of a network user's inputs and off-takes in a portfolio. The imbalances of the portfolio will be billed to the Balancing Responsible Party. Every consumption or injection has to be administered in a portfolio.

Balance Responsible Party

A market- related entity or its chosen representative responsible for its imbalances.

Balancing Services

A service provided to a transmission system operator from a BSP.

Balancing Service Provider

Balancing Service Provider means a Market Participant providing Balancing Services to a TSO.

Constraints/Congestion Management

Set of actions that the network operator performs to avoid or relieve a deviation of the electrical parameters from the limits that define the secure operation. This term includes congestion management and voltage control.

Critical Peak Pricing (CPP)

Day-ahead dynamic tariffs often developed for both residential and commercial consumers. Prices or offering financial incentives are offered end-consumers to cut demand for a set number of hours on days when critical peaks in consumption are expected, usually due to exceptionally hot or cold weather. Both the numbers of days on which a peak can be called and the number of hours are known beforehand and regulated at a regional or national level. By their nature, they occur at irregular intervals in either winter or summer and come under the heading of dynamic peak shifting.

Demand Side Flexibility (DSF)

The changes in energy usage by end-use customers (domestic and industrial) from their current/normal consumption patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in organized electricity markets.

Demand Response (DR)

The planning, implementation, and monitoring of activities designed to encourage consumers to modify patterns of energy usage providing DSF, including the timing and level of electricity demand. On the consumer's side, Demand Response is the voluntary changes by end-consumers or producers or at storages of their usual electricity/gas flow patterns - in response to market signals such as time-variable prices or incentive payments.

Demand Reduction

The voluntary or involuntary reduction in electricity demand by end–consumers.

Demand Side Participation

An actor who actively participates in a demand side action either directly, through facilitation, or through receiving the benefits of that demand side action.

Distributed Generation (DG)

'Distributed generation' means generation plants connected to the distribution system; often these are placed at peoples' homes or businesses. Gas production refers to natural gas wells, Biomethane or Power-to-Gas plants connected to the distribution system.

Distribution System Operator (DSO)

The natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity; Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing.

Energy Efficiency (EE)
An actual reduction in the overall energy used, not just a shift from peak periods. Energy efficiency is a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.

Energy Service Company (ESCO)
An ESCO is a commercial company providing a broad range of energy solutions including designs and implementation of energy savings projects, retrofitting, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management.

Energy Storage
Energy Storage can broadly be considered as an activity to take energy whenever and in whatever form it is available, store it in whatever form is best (with our without conversion) and then put this energy back into the system in whatever form is best (with or without reconversion) for use at the time one needs it.

Explicit Demand Response (EDR)
Demand Side Resources compete directly with supply in the wholesale, balancing and ancillary services markets through the services of aggregators or single large consumers. This is achieved through the control of aggregated changes in load traded in electricity markets, providing a comparable resource to generation, and receiving comparable prices.

Frequency Control
Frequency Control - is the capability of a Power Generating Module to control speed by adjusting the Active Power Output in order to maintain stable system Frequency (also acceptable as speed control for Synchronous Power Generating Modules).

Generator/producer

A natural or legal person generating electricity or producing gas; Generating electricity, contributing actively to voltage and reactive power control, required to provide the relevant data (information on outages, forecast, and actual production) to the energy marketplace.

Imbalance Settlement

A financial settlement mechanism aiming at charging or paying Balance Responsible Parties for their imbalances.

Implicit Demand Response (IDR)

Sometimes called "price-based demand response" IDR refers to *time-varying electricity prices* or *time-varying network tariffs* (or both) that reflect the value or cost of electricity and/or transportation in different time periods and the consumer's decision to react to these price differences, depending on their own initiative without a defined requirement to react. These prices are part of their supply contract. **Critical Peak Pricing** (CPP), and **Real Time Pricing** (RTP) are examples of IDR.

Load Profile

The estimated variation of electrical/gas load versus time. A load profile will vary according to customer type e.g. residential, commercial and industrial and/or temperatures and/or week-days. Load profiles are used to convert the monthly/yearly metered consumption data into estimates of daily/hourly or quarter hourly consumption.

Peak shifting/shaving

The flattening of an electricity consumption load curve. The peak demand at midday is e.g. shifted to a different time of the day e.g. early afternoon, when prices are lower. Or the peak demand is reduced through an alternative energy source e.g. electricity production with a diesel generator.

Portfolio Balancing/Allocation

An allocated Volume means an energy volume measured or estimated to be injected or withdrawn from the system and attributed to a Balance Responsible Party, for the calculation of the Imbalance of that Balance Responsible Party.

Price

A schedule of prices for the sale of energy by a supplier or other commercial market participant.

Primary Control Power/ Frequency Containment Reserves

Frequency Containment Reserves mean the operating reserves necessary for constant containment of frequency deviations (fluctuations) from nominal value in order to constantly maintain the power balance in the whole synchronously interconnected system. Activation of these reserves results in a restored power balance at a frequency deviating from nominal value. This category typically includes operating reserves with the activation time up to 30 seconds. Operating reserves of this category are usually activated automatically and locally.

RTP: Real Time Pricing

A consumer hourly price is set to follow the spot market price or perhaps the intraday market price. Prices therefore change on at least an hourly if not 15-minute basis. RTP is a form of dynamic prices.

Reconciliation

Reconciliation accounts for the differences between the attributed quantity of electricity/gas into the balancing portfolio with a load profile and the metered quantity of electricity/gas at the end-user. Reconciliation will be billed from the TSO or DSO to the BRO or supplier and is usually relevant only for load profile customers.

Retailer

The party responsible for selling electricity or gas to an end consumer, also acting as balance responsible parties. Retailers may provide demand side flexibility or aggregation services to end consumers.

Secondary Control Power / Frequency Restoration Reserves

The operating reserves used to restore frequency to the nominal value and power balance to the scheduled value after sudden system imbalance occurrence. This category includes operating reserves with an activation time typically up to 15 minutes (depending on the specific requirements of the synchronous area). Operating reserves of this category are typically activated centrally and can be activated automatically or manually. In these Framework Guidelines, automatically activated reserves refer to reserves activated by an automatic controller.

Smart Appliances

This is defined as an appliance that supports Demand Side Flexibility (DSF):

- It is an appliance that is able to automatically respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);
- The response is a change of the appliance's electricity consumption pattern. These changes to the consumption pattern are what we call the 'flexibility' of the smart appliance; Whereby:
- The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point in time by the consumer or a service provider'.

Supplier
Any natural or legal person who carries out the function of supply; has a contractual agreement with end customer relating to the supply of electricity/gas.

Supply
The sale, including resale, of electricity to customers

System Balancing
All actions and processes, on all timelines, through which TSOs ensure, in a continuous way, to maintain the system frequency within a predefined stability and to comply with the amount of reserves needed per Frequency Containment Process, Frequency Restoration Process and Reserve Replacement Process.

Tariff/Grid Tariff
A schedule of prices for the usage of the grid

Tertiary Control Power/ Replacement Reserves
Operating reserves used to restore the required level of operating reserves to be prepared for a further system imbalance. This category includes operating reserves with activation time from 15 minutes up to hours.

Transmission System Operator
A natural or legal person responsible for operating, ensuring the maintenance of, and if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity. Moreover, the

TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.

Users of flexibility: – all users of the electricity system who offer and require flexibility services;

Valley Filling
The flattening of an electricity/gas consumption load curve. Load is shifted from peak times to low/zero demand times e.g. in the night.

Voltage Control
A distribution system control managed by distribution system operators in order to maintain voltage in their networks within limits and to minimise the reactive power flows and consequently, technical losses and to maximise available active power flow.